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THE BIOLOGIC AND ECONOMIC ASSESSMENT OF PHORATE AND TERBUFOS

Report of the Phorate and Terbufos Assessment Teams

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Preface

This report was a joint project of the United States Department of Agriculture and State Land-Grant Universities. It was prepared by a team of scientists from these organizations to provide sound, current scientific information on the benefits of phorate and terbufos to United States agriculture. This report is a scientific presentation that may be used in a benefits and risks assessment under the Special Review process required by the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA) as Revised in October 1988.

The Extension Service/NAPIAP staff would like to express their sincere appreciation to the members of the phorate and terbufos assessment teams and to all others who contributed to the preparation of this report. This report could not have been completed without the help of the State Cooperative Extension Service and Experiment Station personnel who provided the usage data used in the analysis. The leadership of the chairpersons, Drs. James S. Bowman and Harold J. Stockdale, and the subteam coordinators, Drs. Rick L. Brandenburg and Susan P. Whitney, was instrumental in completion of this report under an accelerated time schedule. We wish to acknowledge the contributions of Drs. Harry Gaede and E. David Thomas of the U.S. Environmental Protection Agency for their constructive input throughout the preparation of this report. The efforts of the following team members are also acknowledged: Drs. Harold G. Alford and Vernon E. Burton (University of California), Dr. Stanley Coppock (Oklahoma State University), Dr. Osvaldo Cotte (University of Puerto Rico), Dr. Stewart R. Race (Rutgers University), and Dr. Armand L. Padula (Pesticide Assessment Laboratory, USDA-ARS). Members of the USDA/NAPIAP Technical Advisory Group reviewed the final draft of the report and made valuable suggestions for improvements. The preparation of this report required a collective effort by all of the individuals mentioned. A sincere thank you is extended to all.

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Executive Summary

In June 1990, the National Agricultural Pesticide Impact Assessment Program (NAPIAP) began an assessment of the use of phorate and terbufos in United States agriculture. The results of the NAPIAP assessment have been published in this report so that the U.S. Environmental Protection Agency (EPA) will have an overview of the benefits of phorate and terbufos use to United States agriculture. The scope of the report has been limited to an evaluation of the economic benefits to United States agriculture which are obtained from the use of these insecticides, and the social and economic impacts that would likely occur should their use be canceled by federal regulations. Because the health and environmental impacts associated with the use of these insecticides will be evaluated by EPA, these aspects have been discussed in this report only as they relate to United States agriculture.

The economic impact on producers and consumers of agricultural products in the United States caused by the cancellation of phorate would be an annual loss of $21 million (Table 1). Corn and potato producers would sustain the greatest economic loss if phorate is no longer available. The economic impact caused by the cancellation of terbufos would be $127 million, including a loss of $118 million to corn producers and consumers. The aggregate economic effect on producers and consumers caused by the cancellation of both phorate and terbufos would be an annual loss of $168 million. The economic impacts on each commodity are summarized below.

<u>Beans:</u> Phorate is applied to approximately 2% of dry bean acreage and 12% of snap bean acreage in the United States. Only 5 of the 17 major bean producing states use phorate. However, phorate is essential to maintain the economic viability of the industry in Idaho. The use of alternative insecticides would not adversely affect bean yields, but application costs on dry and snap beans would increase about $10 and $3 per acre, respectively. The resulting economic impact caused by the cancellation of phorate would be an annual net loss of $90,000 for dry beans and $235,000 for snap beans.

<u>Corn:</u> Granular insecticides are applied to 38% of U.S. corn acreage. Terbufos, which is applied to 15% of corn acreage, is the predominant soil insecticide used to control corn rootworm, the principle insect pest of field corn. Based on the results of the benefits analysis, the continued registration of terbufos for use on corn is essential. Terbufos is generally considered to be the most efficacious insecticide available for controlling corn rootworms. In addition, terbufos provides excellent protection against wireworms and white grubs. The annual use of terbufos on over 10 million of the 26 million corn acres treated with insecticides is strong evidence that the registration for this insecticide should be maintained. Alternative granular insecticides are currently available for use on field corn, but there is uncertainty regarding their future availability. The cancellation of terbufos would cause yield reductions when corn rootworm infestations are extremely heavy and when terbufos is the only efficacious product available. Yield reductions would be significant in the southeastern states should carbofuran also be canceled due to difficulty controlling infestation by lesser cornstalk borer and nematodes. The discontinued use of terbufos would cause a 5% reduction of yield on treated acreage and would increase treatment costs slightly. Reduced yields would cause prices to rise about 2%. The cancellation of terbufos would result in an aggregated loss of $118 million per year.

Phorate has been registered for use on corn longer than any other soil insecticide. It is several dollars per acre cheaper to use than terbufos, but it is not as effective when corn rootworm populations are high or when environmental conditions are not favorable. Alternative insecticides are available that are more efficacious, but more expensive, than phorate. The economic impact would be minimal if phorate is withdrawn, since it is used on only 3% of the corn acreage treated with granular insecticides. The cancellation of phorate would cause a net loss of about $10 million per year.

The cancellation of both terbufos and phorate would reduce corn yields by 5% on treated acreage, would slightly increase production costs, and would increase corn market prices. The aggregate economic impact caused by the cancellation of these two insecticides would be $146 million.

Cotton: Phorate use in cotton is limited due to the availability of alternative granular and foliar insecticides. Increased use of foliar insecticides may have detrimental effects on beneficial arthropods and present a drift hazard. Alternative insecticides cost about $6 more per acre to apply, but yields are about 3% greater when they are used. The net economic impact would be an increase of $2.3 million per year. However, the primary alternative insecticide, aldicarb, is under Special Review and may not be available to producers in the future.

Peanut: Phorate is used on less than 10% of peanut acreage. Because of its limited usage and the availability of several insecticide alternatives for early and mid-season insect control, the economic impact caused by the loss of phorate would be a loss of $660,000. Although the economic impact of its cancellation would be minimal, there are several other factors that must be considered before a regulatory decision is made: 1) the need to maintain an adequate number of insecticides for control of the insect vector of tomato spotted wilt virus, 2) the remote potential for increased microbial degradation, and 3) the fact that some insecticide alternatives are under Special Review and would no longer be available should their registrations be canceled.

Potato: Phorate is applied to 40% of the potato acreage. In the northeast and north-central production regions, cancellation of phorate would significantly increase production costs and would increase the development of insecticide resistance in populations of Colorado potato beetle and aphids. In the other production regions, cancellation of phorate would increase problems with wireworms on a localized basis. In the major production regions (Idaho, Washington, Oregon, Michigan, Wisconsin and the Red River Valley), cancellation of phorate would lead to a significant increase in the use of foliar insecticides. The greater use of foliar insecticides would increase the potential for pesticide drift and the potential for the development of pest resistance. The use of insecticide alternatives would reduce yield about 1% on treated acreage, but treatment costs would increase $12 per treated acre. The net economic impact would be a loss of $8.6 million per year.

Sorghum: Granular insecticides are applied to 21% of the 11 million acres of grain sorghum grown in the United States. Phorate is used on 11% and terbufos on 25% of the acres treated with granular insecticides. Phorate is a broad spectrum insecticide that is used in all major sorghum producing states. Terbufos is used because it is efficacious and has broad spectrum pest control. Because several chemical alternatives to phorate and terbufos are available, yield reductions would be 2% and production costs would increase about $1 per treated acre if both insecticides were canceled. The net economic impact caused by the cancellation of both phorate and terbufos would be a loss of $2.3 million. The major pest of sorghum, greenbug, can be controlled with granular insecticides applied at planting or with foliar insecticides applied

later in the season. However, sorghum greenbug control is more difficult with foliar insecticides because they must be applied at the proper time. Pest resistance would be a greater problem should both phorate and terbufos (both organophosphates) be canceled, since only carbofuran and aldicarb (both carbamates) would remain as control alternatives.

Soybean: Early season insect control in soybeans is very limited. As a result, phorate and other at-plant insecticides are rarely used. The cancellation of phorate would have a negligible economic impact on the soybean industry.

Sugarcane: Phorate is applied to approximately 81,000 acres (32%) of the sugarcane that is replanted in the United States each year. Phorate accounts for 60% of soil insecticide usage on replanted sugarcane in Florida, the only state in which it is registered for use on sugarcane. Phorate is the predominant granular soil insecticide used on replanted sugarcane to control corn wireworm because it provides effective control of this serious pest at a reasonable cost. Alternative insecticides are available and provide similar control, but several of these are undergoing Special Review. Effective non-chemical management alternatives are available, but are not always practical. The cancellation of phorate would have negligible impact on yield or treatment costs.

Sugarbeet: Phorate is applied to 4% of the U.S. sugarbeet acreage. The use of alternatives would result in a 1% decline in yield and a $23 per treated acre increase in application costs. The economic impact of phorate cancellation would be $1.4 million.

Terbufos is applied to 24% of the acreage. The discontinued use of terbufos would result in a 2% decrease in yield, an increase application cost of $13 per treated acre, and a 2% increase in sugarbeet prices (assuming that sugar import quotas do not change). The net economic impact of the cancellation of terbufos would be $8.8 million.

The loss of both pesticides would reduce yields 2.5%, increase production costs $15 per acre, and increase sugarbeet prices 3% (assuming that sugar import quotas do not change). The net economic impact would be a $12 million loss.

Wheat: Phorate is applied to 0.4% of the U.S. wheat acreage. The cancellation of phorate would have little impact on wheat production but application costs would increase resulting in a loss of $171,000.

Impacts on Wildlife

There does not appear to be a significant threat to wildlife due to direct exposure and ingestion of phorate and terbufos granules if the granules are incorporated into the soil according to label recommendations. A NAPIAP survey of 154 individuals representing federal and state agencies in 50 states found 11 incidents of wildlife mortality caused by phorate and 4 incidents caused by terbufos. Eight of the 11 wildlife mortality incidents involving phorate and all 4 of the incidents involving terbufos were associated with heavy rains that resulted in runoff or flooding. The labels of phorate and terbufos should be modified to limit or restrict their use on sites that have a high potential for flooding or excessive runoff into wetlands. Phorate and terbufos pose a minimal threat to wildlife when they are properly incorporated into the soil and when the potential for flooding or excessive runoff is not great.

Table 1. Summary of average annual phorate and terbufos usage in the United States on commodities surveyed, 1985-89, and estimated impacts caused by cancellation of their registrations[a]

Chemical and crop	Extent of use: Area treated	Extent of use: Total chemical used	Extent of use: % of usage	Impacts if chemical canceled: Number of[b] viable alternatives	Impacts if chemical canceled: Change in yield	Impacts if chemical canceled: Net economic impact	Comments
	(%)	(thousand lb ai/yr)			(%)	(thousand $)	
Phorate							
beans							
dry	1.5	23	0.4	1 (1)[c]	0.0	-235	
snap	12.0	26	0.5	1 (1)	0.0	-90	
corn	3.4	2,207	41.4	5 (2)	-0.7	-10,253	
cotton	4.1	290	5.4	3 (2)	+3.2	+2,299	
peanut	9.8	142	2.7	3 (2)	+0.2	-660	
potato	43.4	1,651	31.0	3 (1)	-0.3	-8,590	Incr. production costs and greater potential for pest resistance.
sorghum	2.3	289	5.4	4 (3)	-2.1	-1,537	
soybean	0.1	59	1.1	2 (2)	0.0	0	
sugarbeet	3.8	53	1.0	3 (1)	-1.0	-1,430	
sugarcane	32.0[d]	304	5.7	2 (1)	0.0	+12	
wheat	0.4	284	5.3	2 (1)	0.0	-171	Minimal impact on yield in midwest and west; major impact in southeast.
Total		5,328	100.0			-20,655	
Terbufos							
corn	15.0	9,783	90.7	5 (2)	-5.4	-118,023	Yield loss greater where corn rootworm is severe.
sorghum	5.2	651	6.0	4 (3)	-1.2	-165	
sugarbeet	24.2	348	3.3	3 (1)	-2.1	-8,815	
Total		10,782	100.0			-127,003	

[a]Source: NAPIAP Phorate and Terbufos Surveys, 1990.
[b]Number of alternative insecticides that control the same insect complex as the review chemical.
[c]Number in parentheses is the number of viable alternatives that are currently under Special Review.
[d]% replanted acreage treated. Sugarcane is replanted every three years in Florida. Phorate is used on 60% of the replanted sugarcane acreage in Florida, the only state where it is registered for use on sugarcane.

Introduction

James S. Bowman

This pesticide use assessment report contains detailed information and general conclusions regarding the use of phorate and terbufos insecticides in United States agriculture. It provides an overview of the uses of both insecticides, and describes the economic and social benefits of those uses to United States agriculture. This assessment was prepared by a team of scientists drawn from the agricultural scientific community as a contribution to the review process mandated by the Federal Insecticide, Fungicide, and Rodenticide Act as revised in October 1988.

Phorate and terbufos are used to control a number of important crop pests. When assessing the impacts of the cancellation of their registrations, it should be remembered that two alternatives to phorate and terbufos, aldicarb and carbofuran, are currently undergoing Special Review by the Environmental Protection Agency (EPA). Phorate and terbufos are manufactured by the American Cyanamid Company of Wayne, New Jersey. Phorate and terbufos are marketed under the trade names Thimet® and Counter®, respectively, by the American Cyanamid Company.

Assessment Methodology

In January 1990, the National Agricultural Pesticide Impact Assessment Program (NAPIAP) requested all states and territories in the United States to submit information on the uses of phorate and terbufos by their agricultural industries. In May 1990, NAPIAP began forming a team to conduct an assessment of the benefits of phorate and terbufos use in United States agriculture. The members of the assessment team were chosen to provide a diversity of experience with the crops, insect management practices, and geographic production regions in which phorate and terbufos are used. The assessment team met in June 1990 to develop a detailed survey form (Appendix I) to send to all of the U.S. states and territories that reported significant usage of phorate or terbufos in the January 1990 survey. The survey that they developed requested the following information: 1) the 5-year average (1985-1989) acreage of each crop that is treated with granular formulations of phorate or terbufos, 2) the number of acres treated with phorate, terbufos, or alternative insecticides registered for the same usage, 3) the estimated change in usage if the registrations of phorate and/or terbufos were canceled, and 4) the estimated change in yield if the registrations of phorate and/or terbufos were canceled.

Limitations of the Assessment

Expert opinion was utilized in this pesticide use assessment when empirical insecticide use and pest loss data were not available. There is always some uncertainty attached to subjective estimates. However, the professional experience of members of the assessment team ensure that their benefits and use estimates closely reflect actual use of phorate and terbufos in United States agriculture.

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[illegible]

[illegible] January 1993 the National [illegible] of states [illegible] and tobacco [illegible] to control [illegible] agriculture. The [illegible] the [illegible] phorate [illegible] survey form [illegible] usage [illegible] that is treated with phorate [illegible] treated with phorate [illegible] the [illegible] and 4) estimated [illegible] assessed.

Limitations of the Assessment

[illegible] was utilized [illegible] [illegible] There [illegible] however, the [illegible] and use estimates closely reflect [illegible]

Characteristics and Usage Patterns of Phorate

Phorate is a highly toxic organophosphorus systemic insecticide that was first registered by the American Cyanamid Company in 1956 as a seed treatment for the control of early season thrips on cotton. It is currently marketed as a soil and systemic insecticide for the control of various insect pests on beans, field corn, sweet corn, cotton, peanut, potato, sorghum, soybean, sugarbeet, and wheat.

Pests controlled by phorate include: mites, aphids, greenbugs, thrips, leafhoppers, leaf miners, corn rootworm, psyllids, cutworms, Hessian fly, wireworms, flea beetles, whiteflies, lygus bugs, seedcorn maggots, white grubs, seedcorn beetles, chinch bugs, European corn borer, Colorado potato beetle, root maggots, Mexican bean beetle, and grasshoppers. Approximately 5.3 million lb ai of phorate is used each year in the United States. The following information was derived from the Material Safety Data Sheets for phorate (American Cyanamid Co., 1987 and 1989).

Physical and Chemical Properties

<u>Product Identification</u>

Trade names:	Thimet 15G Soil and Systemic Insecticide; Thimet 20G Soil and Systemic Insecticide.
Synonyms:	Phorate; O,O-diethyl S-[(ethylthio)methyl] phosphorodithioate.
Chemical family:	Organophosphate Molecular formula: $C_7H_{17}O_2PS_5$ Molecular wt: 260.37

<u>Hazardous ingredients</u>

Component	CAS no.	%	TWA/ceiling (mg/m^3)
phorate	000298-02-2	15 & 20	0.05 (skin) 0.2 (STEL)

<u>Granular formulations</u>

Appearance and odor:	Brown to gray granules; mercaptan odor.
Boiling point:	Not applicable.
Melting point:	Not applicable.
Vapor pressure:	Not applicable.
Bulk density:	Thimet 15G - 43-52 lbs/ft^3; Thimet 20G - 50-56 lbs/ft^3.
% Volatility (by vol.):	Not applicable.
Octanol/H_2O partition coef.:	Not applicable.
pH:	Thimet 15G - Not applicable; Thimet 20G - 4-7, depending on carrier source.
Saturation in air (by vol.):	Not applicable.
Evaporation Rate:	Not applicable.
Solubility in water:	Negligible.

<u>Fire and explosion properties</u>

Flash point:	Not applicable.
Flammable limits:	Not applicable.
Autoignition temp.:	Not applicable.
Decomposition temp.:	Decomposes on prolonged heating at 120°C or higher.

Toxicological characteristics

Thimet 15G: The active ingredient in this product is an organophosphorus compound. The acute oral LD_{50} for male albino rats is 27 mg/kg and for female rats it is 31 mg/kg. The acute dermal LD_{50} for male albino rabbits is 207 mg/kg and for female rabbits it is 247 mg/kg. This product is considered to be highly toxic by ingestion in a single dose and moderately toxic in single skin applications. This product is mildly irritating to rabbit skin and eyes.

Thimet 20G: The active ingredient in this product is an organophosphorus compound. The acute LD_{50} for male rats is 15.5 mg/kg and for female rats it is 5.1 mg/kg, which indicates that this product is highly toxic by ingestion in single doses. The acute dermal LD_{50} of this formulation ranges from 32.5 to 75 mg/kg in male rabbits, an indication that this product is highly toxic by single skin applications. This formulation is irritating to rabbit eyes and it is highly toxic by this means of exposure. Phorate is absorbed through ocular exposure and can produce systemic effects.

Inhalation toxicity: Airborne phorate in either formulation can be absorbed through the lungs to produce cholinesterase inhibition.

Employee protection recommendations

- Wear freshly-laundered, long-sleeved work clothing.
- Wear rubber boots or rubber shoe coverings, rubber gloves, and goggles while transferring from package to equipment.
- Rubber gloves should be washed with soap and water after each use. Do not wear the same gloves for other work. Replace gloves frequently.
- Administer a cholinesterase blood test program at workplace. In case of contact, immediately remove contaminated clothing and wash skin thoroughly with soap and water.
- Launder clothing before reuse. Wash thoroughly with soap and water before eating or smoking. Shower at the end of the work day and change clothing.
- Wear a face mask or other respiratory equipment while emptying bags into hopper. Pour downwind and allow as little free fall as possible while emptying bags into equipment. DO NOT BREATHE THE DUST.

Spill and leak procedures

Place spilled material in a covered drum or other container while wearing proper protective equipment (listed above in Exposure Control Section). Liquid chlorine bleach may be used to decontaminate the spill area. Dispose of waste in accord with local, state and federal regulations.

Mode of Action

Except where noted otherwise, the following information was derived from Extoxnet (Michigan State University, 1989a). Phorate is a highly toxic organophosphorus insecticide and acaricide. It is a cholinesterase inhibitor that is slowly degraded by microorganisms and interaction with water. It controls pests by systemic, contact, and fumigation action.

Toxicological Characteristics of Technical Phorate

Acute oral toxicity: Male rat LD_{50} is 1.6 to 3.2mg/kg (American Cyanamid Company, 1990); Mouse LD_{50} is 3.5 to 6.59 mg/kg; Guinea pig LD_{50} is 20 mg/kg. Phorate is highly toxic by ingestion in single doses.

Acute dermal toxicity: Rat LD_{50} is 5.7 mg/kg; rabbit LD_{50} is 5.2 mg/kg; Guinea pig LD_{50}, 20-30mg/kg during a 24-hour exposure. Phorate is highly toxic by dermal exposure.

Acute inhalation: During a 1-hour exposure, rats had an inhalation LC_{50} of 11 mg/m^3. Phorate is moderately toxic by inhalation.

Chronic Toxicity

Reproductive effects: Long-term studies of mice fed high doses of 98.7% phorate showed no effects on fertility, gestation, and viability. This suggests that phorate is unlikely to cause reproductive effects in humans.

Teratogenicity: No adverse effects were found in a teratology study in the rat. Although this suggests that phorate does not cause birth defects, more information is needed to confirm this conclusion.

Mutagenicity: Available mutigenicity studies involving microbial and mammalian cells have shown no adverse effects on genes or chromosomes. Thus, it appears that phorate does not cause mutations.

Carcinogenicity: Valid studies on the carcinogenicity of phorate are not available.

Organ toxicity: Phorate, like other organophosphates, interferes with the working of the nervous system by inhibiting a vital chemical, cholinesterase. In one study, dogs were fed moderate to high doses of phorate six days each week for 13-15 weeks. The dogs experienced lower cholinesterase activity, but did not show any tissue damage. Other studies indicated that direct eye exposure may cause blurring, tearing, and ocular pain.

Fate in Humans and Animals: The major breakdown products of phorate in mammals are more toxic and have greater anticholinesterase activity than phorate. The most toxic metabolite of phorate has an oral LD_{50} of 0.5 to 0.8 mg/kg. Phorate is readily absorbed by the skin and the gastrointestinal tract. In rats, less than 40% of a high oral dose of phorate was excreted in six days. The liver, kidney, lung, brain, and glandular tissue held the remaining residues.

Ecological Effects

Nontarget Toxicity: Phorate is highly toxic to, and extremely fast acting on, bird species, freshwater fish, and aquatic invertebrates. Symptoms occurring in mallards at very low doses include tremors and wing-beat convulsions. Fish which have been studied include the bluegill and rainbow trout.

Bioaccumulation: Phorate has low water solubility, is fat soluble, is slowly degraded and slowly eliminated in the body and thus it has a moderate to high potential to accumulate within organisms.

Environmental Fate

Degradation: Phorate is degraded by microorganisms and interaction with water.

Crop residues: Phorate, itself, is not persistent in plants. However, the breakdown products of phorate persist in plants and soil. In a field study of corn treated with a 10% granular formulation of phorate at 1 lb ai/A, phorate residues were very low after 14 days, yet degradation products persisted for 28 days. After 83 days, no detectable phorate or breakdown product residues were detected in kernels, cobs, or husks.

Soil residues: Soil treatment with insecticides often leaves more residue in plants than does foliar treatment because the compound persists in the soil and is taken-up by the root systems of plants. Phorate binds to soil organic matter and clay particles and is almost immobile in soils. For this reason it does not leach easily; movement of phorate is primarily through run-off with sediment and water. Phorate is moderately persistent in the soil. It has a half-life of 82 days under aerobic laboratory conditions, and 7.5 days under field conditions. It is least persistent in clay soil, while it is slowly released from peat/sand and sandy soils. Phorate disappears within one year from sand/muck soils.

Characteristics and Usage Patterns of Terbufos

Terbufos is a highly toxic organophosphorus systemic insecticide and nematicide that was first registered by the American Cyanamid Company in 1974 as a 15G for the control of corn rootworms on field corn. It is currently marketed for the control of various insect and nematode pests on field corn, popcorn, sweet corn, sugar beets, and sorghum.

Pests controlled by terbufos include: corn rootworms, wireworms, billbugs, seedcorn maggots, seedcorn beetles, white grubs, flea beetles, thrips, aphids, greenbug, root maggot, symphylans, and nematodes. Approximately 10.8 million lb ai of terbufos is used each year in the United States. The following information was derived from the Material Safety Data Sheets for terbufos (American Cyanamid Company, 1986 and 1989a).

Physical and Chemical Properties

Product Identification

Trade names: Counter 15G Systemic Insecticide Nematicide; Counter 20CR Systemic Insecticide Nematicide.
Synonyms: Terbufos; (S-[[91,1-dimethylethyl)thio]methyl] O,O-diethylphosphorodithioate.
Chemical family: organophosphate
Molecular formula: $C_9H_{21}O_2PS_3$
Molecular wt: 288.43

Hazardous ingredients

Component	CAS no.	%	TWA/ceiling (mg/m^3)
terbufos	013071-79-9	15.5	0.05 (skin) 0.2 (STEL)
		20.7	0.05 (skin)

Granular Formulations

Appearance and odor:	Counter 15G: Buff-color free flowing granules; mercaptan-like odor. Counter 20CR: Small brown pellets; mercaptan-like odor.
Boiling point:	Not applicable.
Melting point:	Counter 15G: Not applicable. Counter 20CR: Not available.
Vapor pressure:	Counter 15G: Not applicable. Counter 20CR: 1.8 X 10^{-4} mmHg at 20°C.
Bulk density:	Counter 15G: 43-52 lbs/ft^3. Counter 20CR: Not available.
Vapor density:	Not applicable.
Volatility (by vol.):	Counter 15G: Negligible. Counter 20CR: Not available.
Octanol/H_2O partition coef.:	Not applicable.
pH:	Not applicable.
Saturation in air (by vol.):	Not applicable.
Evaporation rate:	Counter 15G: Negligible. Counter 20CR: Not applicable.
Solubility in water:	Counter 15G: Negligible. Counter 20CR: 10-15 ppm ai.

Fire and explosion properties

Flash point:	Not available.
Flammable limits:	Not available.
Autoignition temp.:	Not available.
Decomposition temp.:	Not available.

Toxicological characteristics

Counter 15G: The acute oral LD_{50} of this product in the male albino rat is 11.7 mg/kg, which indicates the material is highly toxic by ingestion in single doses. Toxicity is primarily related to inhibition of cholinesterase activity. The acute dermal LD_{50} of this product in the male albino rabbit is 10.2 mg/kg which indicates the material is highly toxic by single skin applications. Repeated exposure may effect inhibition of cholinesterase activity. This product is hazardous if exposed to the eyes and may be absorbed through the conjunctiva to produce cholinesterase-inhibition. Airborne Counter can be absorbed through the lungs to produce cholinesterase-inhibition.

Counter 20CR: The acute oral LD_{50} for the combined sexes in rats was calculated to be 29 mg/kg indicating that the materials are highly toxic by the oral route of administration. The acute dermal LD_{50} in male rabbits was shown to be 182 mg/kg indicating that the material is highly toxic by single skin application. This product is mildly irritating to rabbit eyes and non-irritating to rabbit skin.

Employee protection recommendations

Counter 15G: Wear freshly-laundered, long-sleeved work clothing daily. Wear a clean cap, rubber or cotton gloves, and goggles while transferring from package to equipment. If cotton gloves are used, they must be laundered or discarded after each day's use. Do not wear the same gloves for other work. Destroy and replace gloves frequently. In case of contact, immediately remove contaminated clothing and wash skin thoroughly with soap and water. Launder clothing and decontaminate shoes before reuse. Wash thoroughly with soap and water before eating or smoking. Bathe at the end of the work day, and change clothing. Pour downwind and allow as little free fall as possible while emptying bags into equipment. Do not pour at face level and DO NOT BREATHE THE DUST.

Counter 20CR: Wear a face mask or other respiratory equipment while emptying bags into hopper. Pour downwind and allow as little free fall as possible while emptying bags into equipment. DO NOT BREATHE THE DUST.

Spill and leak procedures:

Place spilled material in a covered drum or other container while wearing protective equipment (listed above in Exposure control section). Liquid chlorine bleach may be used to decontaminate the spill area. Dispose of waste in accord with local, state and federal regulations.

Mode of Action

Except where noted otherwise, the following information was derived from Extoxnet (Michigan State University, 1989b). Terbufos is a highly toxic organophosphorus systemic insecticide and nematicide. It is a cholinesterase inhibitor, a chemical critical to normal functioning of the nervous system. It controls pests by systemic, contact and fumigation action.

Toxicological Characteristics of Technical Terbufos

Acute oral toxicity: Male rat LD_{50} is 9.2 mg/kg and female rat is 9.0 mg/kg; male mice is 3.5 mg/kg and female mice is 9.2 mg/kg; male dog is 4.5 mg/kg and female dog is 6.3 mg/kg (American Cyanamid Company, 1990). Rabbits given a single dose of 0.1 mg to the eyes died within 2 to 24 hours after dosing.

Acute dermal toxicity: Rabbit LD_{50} is 1.1 mg/kg for 24 hours, and 1.0 mg/kg in male rats.

Acute inhalation: No information found.

Chronic toxicity

Reproductive effects: In a long-term study in rats, no effects were observed after daily exposure to low doses of terbufos. In a six-month study, no reproductive effects were observed in rats given higher doses. Thus, terbufos appears unlikely to cause reproductive effects in humans.

Teratogenicity: Except in extreme situations, terbufos does not cause birth defects in animals, and this is also expected to be the case in humans. In one study, high doses of terbufos were administered to pregnant rats via a stomach tube during the sensitive period of gestation. No changes in fetal appearance or behavior were observed even though some of the mothers showed toxic effects, such as lower body weights. In a similar study on rabbits, no significant differences in fetal development were observed except in the offspring of rabbits given the highest dose. These females showed toxicity to the dose level, and their offspring tended to have an extra main artery.

Mutagenicity: Studies have shown that high doses of terbufos may injure cells, but it does not cause permanent changes in chromosomes. Terbufos caused cell damage, but no chromosomal abnormalities, in hamster ovary cells tested for mutagenicity. Terbufos, thus, is unlikely to cause mutations.

Carcinogenicity: No carcinogenic status for terbufos has been established because too few animals have been tested. However, no tumors were found in studies of mice fed for 18 months and rats treated for 24 months at high dosages.

Organ toxicity: Because terbufos inhibits cholinesterase, this pesticide can affect the eyes, lungs, skin, and central nervous system. These effects are dependent on concentration and the route of exposure. In a 28-day feeding study of dogs given terbufos for 6-7 days per week, cholinesterase activity was inhibited 79% in the fluid part of the blood but not in the red blood cells. In a 90-day feeding study using rats, no effects on cholinesterase activity were seen at high doses. In mice given terbufos daily at high levels for 18 months, no changes in liver, kidney, heart, or lung were noted.

Fate in humans and animals: In rats given a single oral dose of terbufos, 10% remained in the liver six hr after dosing. Breakdown products were found in the rat kidney 12 hr after dosing. Of the original dose administered, 83% was excreted in the urine within seven days and 3.5% was found in the feces. The excreted materials contained metabolites of terbufos, not the parent compound. Thus, terbufos is readily degraded in the body.

Ecological Effects

Nontarget Toxicity: Terbufos is extremely toxic to fish (including bluegill sunfish, and trout), birds, and other wildlife.

Bioaccumulation: Terbufos has low water solubility, is stored in fat tissues, tends to be slowly degraded and eliminated by the body and has the potential to accumulate.

Environmental Fate

Crop residues: Terbufos translocates from the soil into plants where it is broken down rapidly. Little of the parent terbufos compound is found in plants. Fifty-seven days after seeding and application, the total residues in broccoli were very low, while the marketable heads of broccoli harvested 90 days after seeding held only traces (less than 0.01 pm, fresh weight) of residues. Under the same conditions, marketable cabbage and cauliflower had trace to nondetectable levels of total residues. Field corn banded with 1.12 kg/ha had no detectable residues 60 days after treatment. Sweet corn and popcorn grain harvested at maturity also showed no residue even though the surrounding soil contained 10-14 ppm.

Soil residues: Terbufos is moderately persistent in the soil. Terbufos is rapidly converted to its metabolites which tend to persist in the soil and may be detected at harvest-time. Terbufos and its metabolites quickly degrade during the first 15-30 days after application, then gradually stabilize. Only 3% of the original application stayed in field-study soils after one month, with 1.5% of the chemical present after 60 days. In a study on silty clay loam soil in South Dakota, the half-life of terbufos was about two weeks. The half-life for the metabolite, terboxon sulfone, was two to three times longer. When applied to a silt loam soil, the half-life for terbufos was calculated at 15 days, while the total residue half-life was 22 days. After 106 days, the total residues were less than 1.0 ppm. Terbufos dissipation is generally faster in soils with less than two percent organic carbon, while binding increases with increasing organic carbon content. Sandy soils lose more of this chemical than more clay-like soils over the same time period. Overall, terbufos is immobile in the soil. Much of the chemical can be recovered near the site of application. In one study, over 90% of applied terbufos was recovered in the top four inches of the soil profile despite heavy rainfall and thorough incorporation down to two-and-one-half inches. Soil moisture does not appear to affect the degradation of terbufos. This chemical will degrade at about the same rate regardless of moisture content. Terbufos degrades more quickly as temperature increases.

Groundwater contamination: Because it has a low water solubility, terbufos is not often found in groundwater. Terbufos has been found in 9 of 283 groundwater samples collected from 261 locations in five states. The maximum concentration found was 3 µg/l.

Phorate Use on Beans

Richard E. Johnson

Bean (*Phaseolus* spp.) production in the United States can be divided into dry edible and snap beans. Based on production data for the past five years, the dominant classes of dry edible beans are (in decreasing order of harvested acreage): pinto, navy, great northern, red kidney, pink, blackeye, baby lima, large lima, small red and small white (USDA, 1990b). The major United States dry edible bean producers are Michigan, Nebraska, Idaho, California, Colorado, and North Dakota. The major producers of snap beans are Wisconsin, Oregon, Illinois, New York, and Michigan. Production of dry edible beans ranged from 8.8 million cwt for pinto beans to 0.4 million cwt for small white beans. The United States production of all classes of dry edible beans averaged 1,483 cwt/acre from 1984-89 (USDA, 1990b). The average annual value was nearly $449 million. The average annual value of snap beans was in excess of $107 million. The average market price for dry edible beans may fluctuate as much as 50% among production regions and from year to year. The price of snap beans is also quite variable, but is more stable than the price for dry edible beans.

Registration Summary

Phorate is registered for at-planting applications on beans for control of Mexican bean beetle (*Epilachna varivestis* Mulsant), leafhoppers (primarily *Empoasca fabae* [Harris]), aphids (Aphididae), lygus bug (*Lygus lineolaris* [Palisot de Beauvois]), thrips (Thripidae), spider mites (Eriophyidae), and seedcorn maggot (*Delia platura* [Meigen]). Phorate is incorporated into the soil at planting in the seed furrow, as a band, or it is sidedressed.

Pest Infestation and Damage

The insect pests of dry edible beans and snap beans are similar, but their importance varies among United States production regions. The major insect pests of beans are: the seedcorn maggot, the Mexican been beetle, lygus bugs (especially the tarnished plant bug (*Lygus lineolaris* [Palisot de Beauvois]), thrips (especially onion thrips *Thrips tabaci* Lindeman), leafhoppers (especially the potato leafhopper *Empoasca fabae* [Harris]), and the beet leafhopper (*Circulifer tenellus* [Baker]), aphids (pea aphid *Acyrthosiphon pisum* [Harris] and green peach aphid *Macrosiphus euporbiae* [Thomas]), several species of flea beetles and wireworms, and white grubs (especially *Phyllophaga* spp.). There are several other insects that are major pests of beans in certain states: grasshoppers in Montana; western bean cutworm (*Loxagrotis albicosta* [Smith]) in Colorado, Nebraska and Wyoming; cutworms (species unspecified) in Utah and Nebraska; the cowpea aphid (*Aphis craccivora* Koch) in California; spider mites (especially the twospotted spider mite *Tetranychus urticae* Koch) in Colorado, Idaho Michigan, and Washington; and root-knot nematodes (*Pratylenchus* ssp.) in Michigan.

Pest Management

Current Chemical Usage

The results of the 1990 National Agricultural Pesticide Impact Assessment Program (NAPIAP) Phorate Survey indicate that approximately 3% of bean acreage in the United States is treated with phorate (Table 2). Phorate and its two alternatives, disulfoton and aldicarb, are used on beans as pre-emergence granular insecticides. Phorate is not used on beans in Maine, Maryland, Michigan, Minnesota, Montana, New Hampshire, Nebraska, New York, North Dakota, Utah, Washington and Wyoming.

Idaho uses both phorate and aldicarb for bean seed production. In Idaho, these two insecticides provide excellent systemic control of thrips and mites and good suppression of beet leafhopper. Aldicarb would be used to treat approximately 90% of the treated acreage in Idaho if the registration of phorate were canceled. Phorate would be replaced by aldicarb in Colorado and by disulfoton in Delaware, New York and Ohio. In Wisconsin, usage of disulfoton and dimethoate would increase if the registration of phorate were canceled.

The efficacy of chemical alternatives is dependent on the types and populations densities of insects that are present in a production region. In California, where the usage of at-planting systemic insecticides is small (less than 0.4% of total usage), propargite or dicofol are used to control spider mites, and dimethoate or methomyl are used to control lygus bugs, aphids and leafhoppers. California uses aldicarb on 15% of its bean acreage for control of cowpea aphid, but relies much more heavily on the use of dimethoate foliar sprays.

Chemical Alternatives for Pest Management

There are several insecticide alternatives to phorate that can be used for post-emergence control of bean pests. Acephate, dimethoate and methomyl can be used to control a large number of bean pests (Crop Protection Chemicals Reference, 1989); however, only one (dimethoate) is labeled for control of spider mites. Propargite and dicofol can also be used for spider mite control. Michigan controls seed corn maggots by treating seed with chlorpyrifos and diazinon. North Dakota uses chlorpyrifos and lindane seed treatment for control of both seed corn maggots and wireworms.

Non-Chemical Pest Management Alternatives

Crop rotation is not an effective management alternative since most bean pests migrate from adjoining fields. Great northern and pinto bean varieties with resistance to curly top virus have been released in Idaho (Pfadt, 1985, page 395). Planting dates can be altered to avoid peak populations of beet leafhopper. The use of predatory mites for control of spider mites has been used with variable success (Pfadt, 1985, page 417).

Integrated Pest Management

Only two states, California and Idaho, reported the use of Integrated Pest Management (IPM) strategies in the 1990 NAPIAP Phorate Survey. In California, bean producers use treatment thresholds to avoid insecticide use until pest damage approaches economic levels. The state of Idaho has initiated an IPM program which includes the release of predatory mites.

The use of IPM strategies in drybean production has been published in Colorado (Schwartz and Brick, 1990).

Potential for Pest Resistance

Spider mite populations are developing strong resistance to propargite in Idaho, so this chemical may be effective for only a few more years. If the registration of phorate were canceled, producers in Idaho would not have an effective alternative to propargite for control of spider mites. In Idaho, bean yields may be reduced by 50% and quality may be reduced by 30% if phorate is no longer available due an increase in spider mite resistance.

Summary

Phorate is applied to only 3% of United States bean acreage. However, phorate accounts for approximately 60% of granular insecticide usage in states where it is applied. In Idaho and several other states phorate is used because it is less expensive than aldicarb. The availability of both phorate and aldicarb is considered to be essential for an economically viable bean industry in Idaho. The development of spider mite resistance to pesticides in Idaho makes it imperative that several chemicals be available for control of these bean pests. California uses very little phorate or the alternatives aldicarb and disulfoton, but relies more on post-emergence foliar air or ground spray with dimethoate, acephate, methomyl, dicofol or propargite.

Table 2. Phorate and alternative chemical usage in United States bean production, 1984-88[a]

State and chemical	Area planted	Area treated	Treatment rate	Total[b] chemical used	% of usage
	(acres)	(%)	(lbs ai/A)	(lbs ai/yr)	
California	168,000	0.4		891	100
phorate		0.1	1.1	185	21
aldicarb		0.2	1.5	504	56
disulfoton		0.1	1.2	202	23
Colorado	182,000	0.5		1,092	100
phorate		0.5	1.2	1,092	100
Delaware	16,000	40		6,800	100
phorate		35	1.0	5,600	82
disulfoton		5	1.5	1,200	18
Idaho (seed)	26,000	75		22,230	100
phorate		40	1.2	12,480	56
aldicarb		30	1	7,800	35
disulfoton		5	1.5	1,950	9
Idaho/Oregon	140,333	25		35,084	100
phorate		12.5	1	17,542	50
aldicarb		12.5	1	17,542	50
Michigan (snap)	20,000	30		7,500	100
phorate		15	1	3,000	40
disulfoton		15	1.5	4,500	60
New York	32,100	20		7,704	100
phorate		10	1.2	3,852	50
disulfoton		10	1.2	3,852	50
Ohio (dry)	3,000	15		675	100
phorate		5	1.5	225	33
aldicarb		5	1.5	225	33
disulfoton		5	1.5	225	33
Ohio (snap)	1,500	90		2,024	100
phorate		45	1.5	1,012	50
disulfoton		45	1.5	1,012	50
Wisconsin (dry)	10,000	25		3,750	100
phorate		25	1.5	3,750	100
Wisconsin (snap)	87,000	23		20,010	100
phorate		20	1	17,400	87
disulfoton		3	1	2,610	13
All User States	685,933	15		107,760	100
phorate	63,067	9		66,138	61
aldicarb	28,852	4		26,071	24
disulfoton	13,425	2		15,551	15
U.S. Total[c]	1,757,000	6			
phorate		3			
aldicarb		2			
disulfoton		1			

[a]Source: NAPIAP Phorate Survey, 1990.
[b]Applied once per season.
[c]Source: USDA, 1988 and 1989.

Phorate and Terbufos Use on Corn

Harold J. Stockdale, John F. Witkowski, Michael E. Gray, Susan E. Rice Mahr, Harold R. Willson and Benjamin H. Kantack

Granular soil insecticides are applied to corn (*Zea mays* L.) at planting and during cultivation. These chemicals provide protection against most soil-based arthropod and nematode pests of corn that affect stand establishment, plant vigor, and yield. The relative importance of each pest varies with geography, crop rotation pattern, tillage method, and end use of the commodity (i.e. grain, silage, seed, or sweet corn). Nationally, the corn rootworm larval complex (*Diabrotica* spp.) is the most serious pest (Krysan and Miller, 1986).

Registration Summary

Both phorate and terbufos are registered for use on corn to control western and northern corn rootworms (*Diabrotica virgifera virgifera* LeConte, and *Diabrotica barberi* Smith and Lawrence), wireworms (Elateridae), white grubs (*Phyllophaga* spp.), seedcorn maggot (*Hylemya platura* [Meigen]), seedcorn beetles (*Stenolphus lecontei* [Chaudoir] and *Clivina impressifrons* LeConte), and corn flea beetle (*Chaetocnema pulicaria* Melsheimer). In addition to these insect pests, terbufos is registered for control of symphylans, thrips (Thripidae), maize billbug (*Sphenophorus maidis* Chittenden), southern corn billbug (*Sphenophorus callosus* [Oliver]) and nematodes, and for suppression of cutworms (Noctuidae) and lesser cornstalk borer (*Elasmotalpus lignosellus* [Zeller]). Phorate is also registered for control of spider mite (*Tetranychus urticae* Koch), aphids (Aphididae) and first-generation European corn borer (*Ostrinia nubilalis* [Hübner]). In three states (Colorado, Kansas, and Nebraska) phorate is also registered for control of chinch bug (*Blissus leucopterus leucopterus* [Say]) nymphs. The 1991 phorate labels no longer permit broadcast applications (air or ground) for the control of European corn borer, corn leaf aphids and mites.

Registered chemical alternatives to phorate and terbufos are carbofuran, chlorpyrifos, and fonofos. Ethoprop and trimethacarb are registered for corn rootworm control, but their use has been very limited. Tefluthrin, a synthetic pyrethroid, was registered in 1989 and is expected to compete successfully in the corn-soil insecticide market.

Pest Infestation and Damage

Primary Pests: The severity of corn root damage caused by western and northern corn rootworm infestations is dependent on weather, hybrid variety, and larval population density (Chiang, 1973). There are varietal differences in the ability of corn hybrids to compensate for root damage caused by rootworm larvae (Branson *et al.*, 1983; Steffy *et al.*, 1989). These varietal differences may be related to the availability of soil moisture (Steffey and Kinney, 1988). Where corn is grown continuously, the most commonly used rootworm pest management practice is the use of granular rootworm insecticides applied at planting.

Secondary Pests: Cropping sequence is a major factor in the establishment of many secondary pests of corn (Foster and Tollefson, 1986). Other factors affecting establishment are weather, weed density and type, soil type, planting date, hybrid variety, tillage practices, and the presence of natural enemies. As tillage of corn is reduced, there is a greater incidence of

insect pests causing stand reductions (Gregory and Musick, 1976). When corn follows sod in the rotation, there is a greater problem with wireworms, white grubs, maize billbug, and southern corn billbug. Cutworms, white grubs, and wireworms are a more frequent problem when corn is planted after clover and alfalfa. When corn follows small grains, there is greater potential for damage by wireworm, seedcorn beetles, seedcorn maggot, and northern corn rootworm. Corn grown on sandy soils in the southeast (Alabama, Florida, Georgia, North Carolina, South Carolina) may require chemical protection against nematodes. Although the total acreage requiring protection from nematodes is small, yield losses can be severe (Dickson and Hewlett, 1987).

Pest Management

Current Chemical Usage

The results of the National Agricultural Pesticide Impact Assessment Program (NAPIAP) pesticide use assessment survey represent current chemical usage on 68.5 million acres of corn, nearly the entire U.S. corn acreage. The results of this survey are summarized in Table 3.

Table 3. Phorate, terbufos, and alternative chemical usage on corn in the United States, 1985-89[a]

Chemical	Area planted	Area treated	Area treated
	(thousand acres)	(thousand acres)	(%)
phorate		2,307	3
terbufos		10,102	15
carbofuran		3,087	4
chlorpyrifos		6,635	10
fonofos		3,305	5
tefluthrin		490	1
Total	68,646	26,104	38

[a]Source: NAPIAP Phorate and Terbufos Surveys, 1990.

Assuming that the registrations of the current chemical alternatives to phorate are maintained, the cancellation of phorate for use on corn would not result in a reduction of yield in 74% of those that responded to the survey. The states where corn yield would be reduced by the loss of phorate were (% yield reduction in parentheses): Minnesota (0.3%), New Mexico (1%), North Dakota (1%), Michigan (1%), Nebraska (5%), and Arizona (10%).

Indiana and South Dakota indicated no reduction in yield if terbufos use was canceled and a 1-3% reduction in yield was estimated by the cornbelt states of Iowa, Illinois, Minnesota, Ohio, Wisconsin, Michigan and Missouri. The use of irrigation and continuous production of corn in southwest Kansas and western Nebraska would result in 5% and 15% yield reductions in those states, respectively. Rootworm populations tend to be higher when corn is grown continuously under irrigation (Brooks, 1967), making the availability of terbufos more important under these conditions. If the registrations of phorate and/or terbufos are canceled, it is estimated that the chlorpyrifos market share will increase from 9.75 to 17.1%, fonofos would increase from 4.85 to 8.2%, carbofuran from 4.5% to 6.85, and tefluthrin from 0.7% to 5.4%.

The application rate for soil-applied granular insecticides range from 0.75 to 1.00 lb ai/acre based on 40-inch row spacing. The 1.0 lb ai/acre rate is most commonly used, and is the rate listed on the terbufos and phorate labels. The use of lower application rates of soil insecticides has been studied in efficacy trials conducted over the past 15 years (Boetel *et al.*, 1990; Chaddha and Ostlie, 1990; Gray, 1990; Hein, 1990). In many trials, root protection from corn rootworm infestation at the 0.75 lb ai/acre rate is nearly as good as the protection provided by the 1.0 lb ai/acre rate. The use of lower application rates may gain wider acceptance as environmental and economic concerns escalate within and outside the farming community.

Systemic insecticides, primarily terbufos and carbofuran, are used routinely in sweet corn production in the east and northeastern U.S. to control flea beetles. Control of the corn flea beetle is important because they transmit *Bacterium stewartii*, the causal organism of Stewart's wilt (Chester, 1950).

Terbufos is registered for use on corn to control nematodes, but usage for this purpose is small. The chemical alternatives to terbufos for nematode control are carbofuran and ethoprop. The impact of terbufos cancellation would not significantly impact the control of nematodes on corn if the alternative products remained available. However, significant yield losses from nematode damage could result on very sandy soils in the southeastern U.S. should use of the chemical alternatives to terbufos also be canceled (Dickson and Hewlett, 1987).

Chemical Alternatives for Pest Management

Insecticides registered for treatment of corn seed are available for suppression of wireworms, seedcorn maggot, and seedcorn beetles. The insecticides registered for this use are lindane, chlorpyrifos, and diazinon. There are no effective post-planting rescue treatment alternatives.

Preventative soil treatment for control of cutworms on corn can be applied as granules before or during planting, or in a liquid formulation applied as a tank mix with pre-plant or pre-emergence herbicides. Post-emergent rescue treatments can also be used. Terbufos is registered for cutworm suppression, but it is not generally recommended by the Extension Service due to the difficulty of predicting economic infestations of cutworms. Extension Service recommendations in most states advise producers to use rescue treatments, rather than preplant or planting-time preventive treatments, to control cutworms.

Properly timed foliar insecticide treatments can reduce adult corn rootworm populations, thereby reducing the number of eggs in the soil. A reduction in the number of eggs may eliminate the need to apply a granular insecticide the following season if the field is again planted to corn. This strategy must be managed by properly trained personnel, since it requires a knowledge of population thresholds and insect biology (e.g. number of beetles per plant, male to female ratio, percent gravidity). Two properly timed insecticide treatments are often required to reduce beetle populations since egg-laying can occur as late as September (Hein and Tollefson, 1985a). There are several negative factors associated with the use of these foliar treatments: 1) corn rootworm resistance may develop more quickly; 2) spider mite infestations may increase due to a negative impact on beneficial insects (i.e., pollinators, predators, parasites); and 3) other non-target insects may be impacted. For these and other reasons, producers have not implemented rootworm adult control programs on a large scale.

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[illegible] used to apply a granular [illegible]
[illegible] This strategy [illegible]
[illegible] knowledge of population [illegible]
[illegible] female ratio, pasture [illegible]
[illegible] to reduce beetle population [illegible]
[illegible] 1989a). The [illegible]
[illegible] 1) corn rootworm resistance may [illegible]
[illegible] may [illegible] is due to a negative impact on beneficial [illegible]
[illegible], parasites, and 3) [illegible]
[illegible] producers have not implemented rootworm adult control [illegible]

Non-Chemical Management Alternatives

Northern and western corn rootworm overwinter as eggs in the soil of corn fields, and the larvae then feed on the roots of corn planted the next season. Since corn rootworm larvae cannot survive on soybean roots, an effective control measure is a corn-soybean rotation (Branson and Ortman, 1970). In general, a rotation with a crop other than corn will break the corn rootworm cycle. This commonly used practice eliminates the need for application of soil insecticides for rootworm larval control. However, low levels of corn rootworm damage to first year corn (i.e. corn following soybean or other alternate crops) have been reported by several states in the cornbelt (Hill and Mayo, 1980). The survival of corn rootworm eggs in the soil for more than one year is the result of extended diapause, which has also been found in Nebraska, South Dakota, Iowa, Illinois, and Minnesota (Krysan *et al.*, 1986).

A corn-soybean rotation has been used on several million acres in the midwest for over 20 years. However, the lack of flexibility in the current farm program has reduced the use of rotation because of the potential for loss of program base and payments. The 1990 Farm Bill increases planting flexibility and reduces obstacles to the use of rotation in corn production.

Potential for Pest Resistance

With the currently registered organophosphate and carbamate granular insecticides available for use on corn, the potential for pest resistance is considered minimal. The potential for pest resistance is reduced because organo-phosphate and carbamate insecticides are non-persistent in the environment. In addition, only a small portion of the pest population is exposed to insecticide treatment in a single season because the material is applied in a small 7-inch band and rootworm larvae developing on roots outside the chemically treated band are not exposed to the insecticide. The exposure of only a small portion of the pest population allows susceptible genes to be re-introduced each year (Krysan and Sutter, 1986). The potential for pest resistance is also reduced because western and northern corn rootworms are univoltine.

Outlook for New Chemical and Non-Chemical Controls

The chemical industry remains active in the development of new insecticides for registration and use on corn. However, the increase in development costs and rising environmental concerns make the outlook for the registration of new chemicals questionable. Several midwestern states are involved in a cooperative adult rootworm control research program using starch-borate granules impregnated with several semiochemicals, cucurbitacin, and a very small amount of carbaryl (Lance, 1988; Meinke, 1990). This "attract and kill" approach is a promising rootworm management alternative, but it must still be demonstrated that these formulations will persist through the rootworm egg-laying period.

Non-chemical alternatives such as biological control agents may eventually provide viable alternatives to chemical control of corn pests, but not within the next five to ten years. Two promising areas of research are the isolation of a highly virulent strain of *Beauveria bassiana* and the incorporation of *Bacillus thuringiensis* into the genetic structure of corn through genetic engineering (J. Obrycki, Iowa State University, personal communication).

There have been phytotoxic responses in corn as a result of an interaction between the systemic activity of terbufos and the new sulfonylurea herbicides, Beacon® and Accent® (M. Owen, Iowa State University, personal communication). These new herbicides are particularly useful in production areas where problem weeds such as shatter cane, wooly cupgrass, wire

[illegible] 1989 resistant corn rootworm [illegible]
[illegible] on the roots of corn plants [illegible]
[illegible] on soybean roots [illegible]
[illegible] and Oatman, 1970) [illegible]
[illegible] cycle. This [illegible]
[illegible] corn rootworm larvae [illegible]
[illegible] (i.e., corn following soybean) [illegible]
[illegible] control [illegible] May [illegible]
[illegible] year is the [illegible]
[illegible] Iowa, Illinois, [illegible]

[illegible] population has [illegible]
[illegible], the [illegible]
[illegible] use of the pattern [illegible]
[illegible]

[illegible] Resistance

[illegible] currently [illegible]
[illegible] in corn, the potential to [illegible]
[illegible] reduced because [illegible]
[illegible] in the environment [illegible]
[illegible] to insecticide treatments [illegible]
[illegible] and rootworm larvae [illegible]
[illegible] to the insecticide. The [illegible]
[illegible] generally be [illegible]
[illegible] resistance [illegible]

Chemical and Non-Chemical [illegible]

[illegible] industry [illegible] development [illegible]
[illegible]. However, the [illegible] in development [illegible]
[illegible] the market for [illegible]
[illegible] involved in [illegible]
[illegible] granules impregnated with [illegible]
[illegible] (Levine, 1986; [illegible], 1990) [illegible]
[illegible] alternative [illegible]
[illegible] the rootworm [illegible]

[illegible] alternatives such as [illegible]
[illegible] to chemical control of corn pests, but [illegible]
[illegible] research are the isolation [illegible]
[illegible] Bacillus thuringiensis [illegible]
[illegible] Iowa State University [illegible]

[illegible] pest [illegible] in corn [illegible]
[illegible]

stem muhly or quack grass are common. In fields where a problem weed exists and either Beacon® or Accent® was the herbicide selected, then a non-systemic organophosphate insecticide (chlorpyrifos, fonofos) or a carbamate (carbofuran) or synthetic pyrethroid (tefluthrin) would need to be used to avoid the occurrence of a phytotoxic reaction.

Integrated Pest Management

The implementation of integrated pest management programs (IPM) based on the scouting techniques and economic thresholds recommended in current extension publications would reduce the use of soil insecticides. For example, scouting corn fields for corn rootworm beetles in July, August, and September permits producers to identify fields where the likelihood of economic damage by rootworm larvae is high the following year. When the population of rootworm beetles exceeds 0.7 beetles per plant, an economic infestation is likely if that field is planted to corn the following year. The use of this technique could dramatically reduce the use of soil insecticides at planting and at cultivation, because only those fields with potential for rootworm damage would be treated. Corn producers have not adapted IPM techniques for a variety of reasons: 1) convenience and confidence in at-planting and at-cultivation timed insecticide applications; 2) lack of knowledge or confidence in the adult counting concept as a scouting technique; 3) increased labor requirements; and, 4) shortage of trained insect scouts. However, IPM methodologies have been successfully used by the agricultural consulting industry.

Sticky traps have been proposed as an alternative method for assessing the potential for rootworm infestation the following season (Tollefson *et al.*, 1975). This technique has been refined as a result of subsequent research (Hein, 1984; Hein and Tollefson, 1984; Karr 1984; Hein *et al.*, 1985; Hein and Tollefson, 1985b). Fields are considered to have a high potential for corn rootworm damage the following season if the average number of beetles caught in a trap during a 7-day period exceeds 29 (Tollefson, 1986).

The visual count and sticky trap methods for assessing beetle populations are not commonly used by corn producers. However, these do represent realistic management strategies that could be used singly or in combination to reduce the amount of insecticide applied to continuous corn.

It is estimated that only 20-40% of the acreage planted to continuous corn has corn rootworm infestations that reach the economic level. However, in most instances corn producers do not assess the need for the application of insecticides, preferring to use preventative applications. Preventative applications of insecticides will become less common as corn producers become more concerned with the agricultural environment and the added cost of applying insecticides unnecessarily to 60-80% of their acreage. It is important that extension personnel continue to educate corn producers about the alternative management strategies which will reduce their reliance on chemical control of corn pests.

Comparative Performance Evaluation

Based on root ratings from numerous insecticide screening trials, terbufos is one of the most consistently efficacious soil insecticides for control of western and northern corn rootworm larvae (Boetel *et al.*, 1990; Chaddha and Ostlie, 1990; Hower and Alexander, 1990; Jarvi, 1990). Terbufos and carbofuran are the two most efficacious granular insecticides for control of white grub (McBride, 1984) and wireworm (McBride, 1983; Ostlie *et al.*, 1990). Terbufos is often preferred by no-till corn producers because it can be used in-furrow, unlike many of the alternative chemicals. The in-furrow registration of terbufos may be an advantage when

[illegible] would have to be used to avoid the occurrence [illegible]

[illegible] Pest Management corn

The implementation of integrated pest [illegible] [illegible] control [illegible] [illegible] the use of soil insect[illegible] [illegible] August and September [illegible] damage by rootworm [illegible] exceeds [illegible] [illegible] corn [illegible] following [illegible] [illegible] would be treated [illegible] 1) convenience and [illegible] [illegible] applications, 2) lack of knowledge [illegible] technique, 3) [illegible] required [illegible] PM methodologies have been [illegible]

[illegible] traps have been proven [illegible] [illegible] infestation the following season [illegible] [illegible] as a result of subsequent [illegible] et al., 1985; Hein and Tollefson, 1985b). Field [illegible] corn root worm damage the following season [illegible] [illegible] a 7-day period [illegible] (Tollefson [illegible]

[illegible] count and sticky trap methods [illegible] [illegible] producers. However [illegible] [illegible] singly or in combination to [illegible] [illegible] corn.

[illegible] that only 20-40% of the acreage [illegible] [illegible] that reach the economic level [illegible] not assess the need for [illegible] applications. Preventative applications of [illegible] [illegible] become more concerned with the agricultur[illegible] [illegible] unnecessarily to 40-60% of their acreage [illegible] continue to educate corn producers about the alte[illegible] reduce their reliance on chemical control [illegible]

Performance Evaluation

[illegible] on corn rootworm from numerous insecticide screening trials [illegible] soil insecticides for control of western and northern [illegible] (Sutter et al., 1990; Gaudreau and Ostlie, 1990; Kramer and Alexander [illegible] Terbufos and chlorpyrifos are the two most [illegible] granular insecticides [illegible] [illegible] and wireworm (McLeod [illegible] et al., 1990). [illegible] corn producers because [illegible] [illegible] the rootworm regions [illegible]

surface water-runoff and volatilization of applied insecticides are major concerns (Kenimer *et al.*, 1989).

Phorate is an effective insecticide option for wireworm control, although it is consistently less efficacious for rootworm larvae control compared with other registered products (McBride, 1983; Oleson, *et al.*, 1990).

Summary

Of the 68.5 million acres of corn grown in the United States, 26 million acres (38%) are treated with a soil insecticide to protect against root attacking arthropods. Applications of phorate (9% of usage) and terbufos (39% of usage) account for nearly half of insecticide usage on corn in the U.S. The primary insect pests in continuous corn cropping systems which are controlled with applications of these insecticides are the northern and western corn rootworms.

Terbufos is one of the most, if not the most, efficacious insecticides for the control of corn rootworm on corn. In corn following sod or in no-till production systems, terbufos is clearly the most efficacious insecticide to use. Terbufos and carbofuran are equally efficacious for control of nematodes and the lesser corn stalk borer in the southeastern United States.

The NAPIAP Phorate and Terbufos pesticide use assessment survey produced little or no evidence that yield, producer income or commodity prices would change appreciably if phorate was no longer available for control of corn insect pests. If the registration(s) of phorate (and terbufos) is/are canceled, corn specialists perceive two major effects on corn production:

1. A product with inferior performance capabilities would have to be used in controlling: a) expected heavy infestations of corn rootworms; b) soil insect pests in no-tillage production systems; and, c) lesser corn-stalk borer infestations.

2. Usage of alternative insecticides would increase as follows: carbofuran from 4% to 7% of total usage, chlorpyrifos from 10% to 17%, fonofos from 5% to 8%, and tefluthrin from 1% to 5%.

Corn producers currently utilize several IPM and non-chemical management alternatives as part of their insect pest management programs. Crop rotation will continue to be an important non-chemical management alternative that reduces the number of acres requiring application of insecticides to control corn rootworm. The number of fields that are treated with preventative applications of soil insecticides can be minimized by monitoring the size of adult beetle populations with beetle counts and sticky-traps. Adult monitoring methods are not currently used by corn producers, but promotion by the Cooperative Extension Service and IPM consultants should increase their use by producers.

[illegible] and [illegible] of [illegible]

[illegible] is an effective [illegible] for [illegible] [illegible] control [illegible] 1989)

[illegible] acres [illegible] [illegible] [illegible] usage) [illegible]

[illegible] of the most [illegible] cent. [illegible] [illegible] the [illegible]

[illegible] At. [illegible] [illegible] [illegible] of continuous [illegible] [illegible] needed, [illegible]

[illegible] with infested [illegible] [illegible] heavy infestations [illegible] systems, and [illegible]

[illegible] currently utilized [illegible] IPM and non-chemical [illegible] Crop rotation [illegible] management alternative that reduces the number [illegible] The number of [illegible] insecticides can be minimized [illegible] control [illegible] Adult monitoring [illegible] but promotion by the Cooperative Extension Service [illegible] their use by producers.

Phorate Use on Cotton

Robert B. Head

Cotton (*Gossypium hirsutum* L.) is produced in 15 southern and western states of the United States. United States production is approximately 10-12 million acres, with more than 50% planted in California, Mississippi and Texas (Table 4).

Table 4. United States cotton production, 1988-89[a]

State	Area harvested	Average yield	Total production
	(acres)	(lb/A)	(480 lb bales)
Upland Cotton			
Alabama	358,000	518	385,000
Arizona	294,000	1248	758,000
Arkansas	632,000	721	952,000
California	1,188,000	1108	2,712,000
Florida	29,000	570	34,000
Georgia	295,000	605	370,000
Louisiana	632,000	690	909,000
Mississippi	1,120,000	722	1,688,000
Missouri	223,000	614	286,000
New Mexico	68,000	664	94,000
North Carolina	117,000	552	134,000
Oklahoma	382,000	305	246,000
South Carolina	128,000	560	148,000
Tennessee	490,000	515	527,000
Texas	4,500,000	418	4,008,000
Other	4,000	515	4,000
Total	10,460,000	607	13,253,000
Pima Cotton			
Arizona	186,000	898	348,000
California	10,000	906	10,000
New Mexico	22,000	637	30,000
Texas	58,000	787	96,000
Total	278,000	854	494,000
All cotton	10,738,000	614	13,748,000

[a]Source: USDA, 1990.

Registration Summary

Phorate is labeled for use on cotton for control of thrips (*Frankliniella* spp.), aphids (Aphididae), spider mites (*Tetranychus* spp.), and leaf miners (*Liriomyza* spp.). Phorate is applied at a rate of 0.5 to 1.0 lb ai/acre in the seed furrow at planting. Thrips are the most important cotton pest controlled by phorate.

Pest Infestation and Damage

Certain insect pests are confined to specific production regions (e.g. pink bollworm in the western states), while other pests are endemic across the Cotton Belt (e.g. thrips and plant

bugs). Different insect pests infest cotton at each stage of development (Table 5). Systemic insecticides are frequently applied at planting to provide insect control from plant emergence until the pinhead square stage. Thrips are the primary pest targeted with at-plant applications. Thrips are most damaging during the early stages of cotton development (Head *et al.*, 1990). Thrips feeding on seedling cotton results in stunting, delayed maturity, and reduced yields (Carter, 1989). In addition to the reduction in yield caused by stunting, weed control is more difficult in fields where plant size is reduced. Thrips infested 6.6 million acres of United States cotton in 1987, of which 3.6 million acres were above economic thresholds for foliar treatments (Table 6). In Arkansas, thrips reduced cotton stands by 19%, reduced leaf area by 88%, and delayed fruiting by two weeks (Carter, 1989). The delay in fruiting reduced fiber quality and tensile performance. On high plains cotton in Texas, infestation by thrips from emergence to the appearance of the 4th or 5th true leaf caused a significant reduction in leaf surface area, a delay in square initiation, a reduction in early set squares, a reduction in number of early blooms and bolls, and a reduction of final yield (Leser, 1986). Even with chemical control, thrips reduced cotton yield by 0.36% (Table 6), resulting in a loss of 42,782 bales valued at $15 million (Head, 1990). Cotton yield reduction caused by thrips damage are presented in Table 7. Yield losses in individual production areas may be considerably higher than the average loss, and the average loss would be higher if the reduction in lint quality were factored into loss estimates (Carter, 1989).

Table 5. Mite and insect pests of cotton in the United States

Growth stage & pest	Primary pest	Occasional pest	---Area(s) infested--- south	west	Arizona	beltwide
Emergence to first square						
cutworms	x					x
thrips	x					x
aphids		x				x
spider mites		x				x
plant bugs		x				x
Squaring to bloom						
boll weevil	x		x			
Heliothis spp.	x					x
plant bugs		x				x
fleahopper		x	x[a]			
spider mites		x				x[b]
aphids		x				x
Bloom to harvest						
Heliothis spp.	x					x
boll weevil	x		x		x	
pink bollworm	x			x		
aphids		x				x
plant bugs		x				x
spider mites		x				x[b]
whiteflies		x				x[c]
armyworms		x	x			
leaf miner		x		x		

[a]Most serious in Texas.
[b]Most serious in the western states.
[c]Most serious in Arizona and California.

Table 6. Phorate and alternative chemical usage on cotton, 1989[a]

Insect pest	Area infested	Area above threshold	No. insecticide treatments	Treatment cost	Yield reduction	No. bales lost
	(mil acres)	(mil acres)		($/A)	(%)	
boll weevil	5.9	4.8	2.6	3.85	2.75	331,466
boll and bud worms	7.5	4.7	1.8	7.14	1.87	225,115
fleahopper	4.4	1.0	0.1	3.09	0.11	12,951
lygus bug	4.1	2.3	0.3	4.16	2.05	246,667
leaf perforator	0.2	0.1	0.0	9.04	0.00	267
pink bollworm	0.4	0.3	0.2	8.94	0.14	16,438
spider mites	2.6	1.6	0.2	11.02	1.11	133,838
thrips	6.6	3.6	0.5	4.09	0.36	42,782
beet armyworm	1.2	0.5	0.1	10.47	0.15	18,629
fall armyworm	0.6	0.2	0.0	7.80	0.03	3,596
minor pests	1.0	0.4	0.1	9.86	0.05	5,741
aphids	6.0	3.8	0.8	5.06	0.55	65,805
new pests	0.3	0.2	0.0	8.96	0.03	3,223
white flower thrips	2.2	0.2	0.0	7.36	0.03	3,388
Total	43.0	23.7		37.85	9.22	1,109,906

[a]Source: Head, 1990b.

Table 7. Thrips damage to United States cotton production, 1985-89[a]

State	Area infested	Yield reduction	No. bales lost
	(mil acres)	(%)	
Alabama	355.0	0.45	1,755
Arizona	239.0	0.80	75
Arkansas	568.0	0.48	3,827
California	18.4	0.05	1,600
Florida	22.0	0.36	118
Georgia	144.0	0.21	775
Louisiana	384.1	0.27	2,285
Mississippi	941.6	1.07	15,206
Missouri	155.2	2.57	6,339
New Mexico	52.9	1.92	2,024
North Carolina	82.8	0.49	621
Oklahoma	300.0	0.00	5
South Carolina	114.0	1.62	2,387
Tennessee	360.2	0.73	3,208
Texas	2812.1	0.46	8,873
Virginia	2.2	0.10	2
Total	6551.5		49,100

[a]Source: Head, 1990b.

Pest Management

Current Chemical Usage

Phorate is used on 480,507 acres (4%) of cotton in the United States, requiring the application of 334,548 lb ai costing $2.1 million (Table 8). The percentage of acreage treated ranges from 0 in Tennessee to 42% in Florida. Since the application of phorate does not require an extra trip in the field, the cost of the chemical is the total cost of application. Phorate is applied in the seed furrow at planting, and will give some protection against insect pests for five weeks. There are several granular chemical alternatives to phorate for systemic control of thrips: aldicarb, disulfoton and carbofuran (Fig. 1). However, these insecticides are more expensive and for this reason will increase overall costs of thrips control (Table 9).

Table 8. Phorate and alternative chemical usage on cotton, 1985-89[a]

State & chemical	Area harvested	--- Area treated if: --- Phorate available	Phorate unavailable	Area currently treated	Total chemical used
	(thousand acres)	(%)	(%)	(acres)	(lb ai)
Alabama	358				
phorate		3	0	10,020	7,515
aldicarb		70	70	233,800	105,210
carbofuran		0	0	0	0
disulfoton		15	18	50,100	37,575
Arizona	480				
phorate		10	0	45,000	45,000
aldicarb		30	40	135,000	67,500
carbofuran		2	2	9,000	9,000
disulfoton		2	2	9,000	9,000
Arkansas	632				
phorate		1	0	7,000	3,500
aldicarb		75	76	525,000	262,500
carbofuran		1	1	7,000	7,000
disulfoton		1	1	7,000	7,000
California	1,198				
phorate		8	0	96,528	58,882
aldicarb		14	22	178,206	169,295
carbofuran		0.1	0.1	1,238	817
disulfoton		0.2	0.2	2,475	5,470
Florida	290				
phorate		42	0	10,794	8,096
aldicarb		44	60	11,308	5,654
carbofuran		0	0	0	0
disulfoton		12	38	3,084	2,313
Georgia	295				
phorate		15	0	40,350	30,263
aldicarb		60	75	161,400	80,700
carbofuran		0	0	0	0
disulfoton		5	5	13,450	10,088
Louisiana	632				
phorate		7	0	52,899	46,286
aldicarb		52	57	392,962	196,481
carbofuran		0	0	0	0
disulfoton		5	7	37,785	37,785
Mississippi	1,120				
phorate		2	0	22,000	22,000
aldicarb		35	36	385,000	192,500
carbofuran		0	0	0	0
disulfoton		5	6	55,000	55,000
Missouri	223				
phorate		9	0	20,022	20,022
aldicarb		33	33	70,077	35,039
carbofuran		0	5	0	0
disulfoton		5	7	10,011	10,011
New Mexico	80				
phorate		2	0	1,567	1,567
aldicarb		8	8	5,893	2,947
carbofuran		4	6	3,208	3,208
disulfoton		2	2	1,641	1,231
North Carolina	117				
phorate		1	0	1,180	885
aldicarb		93	94	109,740	65,844
carbofuran		0	0	0	0
disulfoton		3	3	3,540	2,655

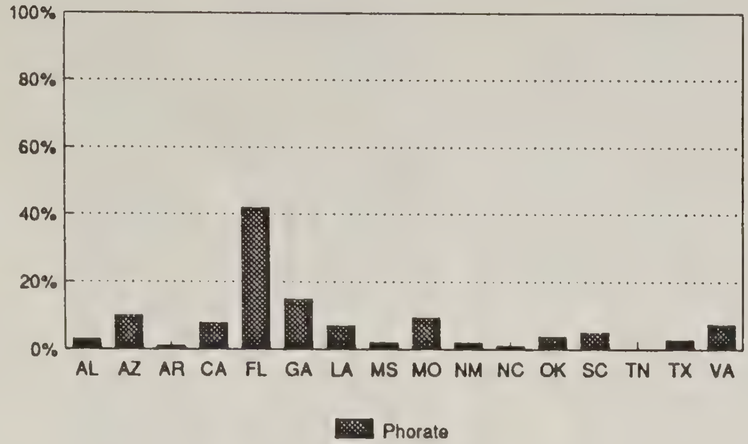
Table 8 (*continued*)

State & chemical	Area harvested	--- Area treated if: --- Phorate available	Phorate unavailable	Area currently treated	Total chemical used
	(thousand acres)	(%)	(%)	(acres)	(lb ai)
Oklahoma	382				
phorate		4	0	15,834	11,876
aldicarb		6	10	23,954	11,977
carbofuran		1	1	4,060	4,060
disulfoton		1	1	4,060	4,060
South Carolina	128				
phorate		5	0	6,140	3,070
aldicarb		70	73	85,960	42,980
carbofuran		0	0	0	0
disulfoton		5	7	6,140	3,684
Tennessee	490				
phorate		0	0	0	0
aldicarb		35	35	148,400	81,620
carbofuran		0	0	0	0
disulfoton		15	15	63,600	50,880
Texas	4,558				
phorate		3	0	150,724	75,362
aldicarb		18	20	974,323	438,445
carbofuran		1	2	75,362	56,522
disulfoton		1	1	26,915	16,149
Virginia	4				
phorate		8	0	450	225
aldicarb		85	92	5,100	2,550
carbofuran		0	0	0	0
disulfoton		8	8	450	225
All User States	10,738				
phorate				480,508	334,549
aldicarb				3,446,123	1,761,242
carbofuran				99,868	80,607
disulfoton				294,251	253,126

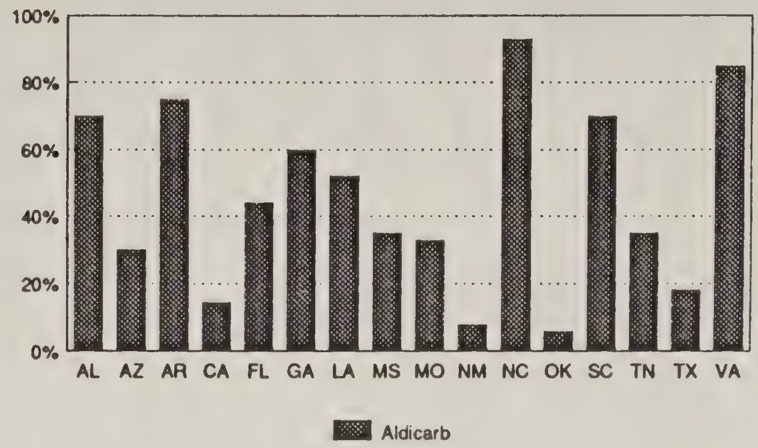
[a]Source: NAPIAP Phorate Survey, 1990.

Figure 1

% of acres treated with Phorate

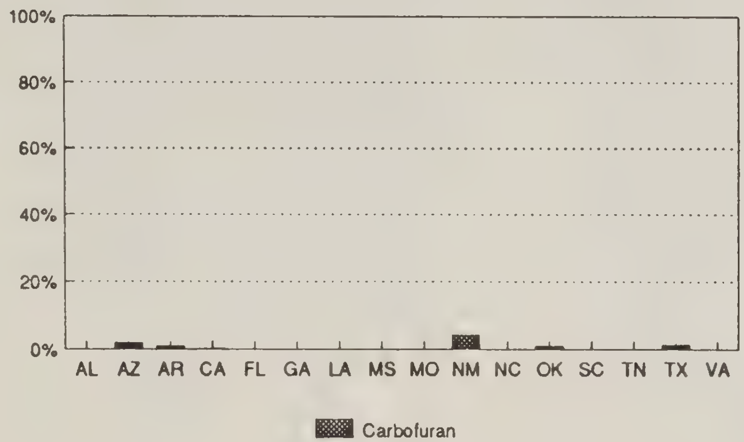


% of acres treated with Aldicarb

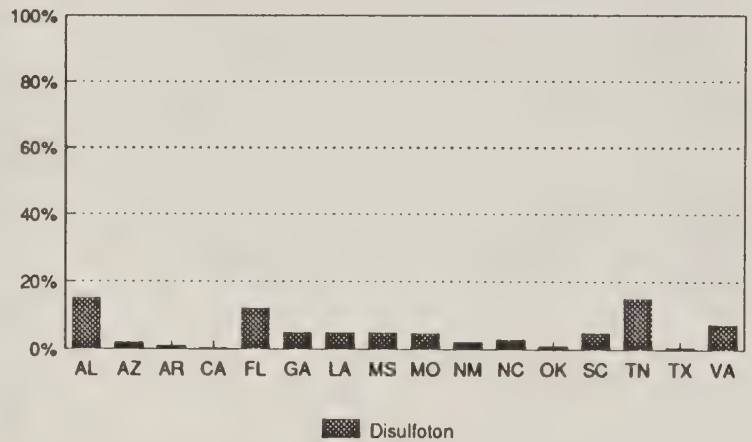


Cotton Production Chemicals

% of acres treated with Carbofuran



% of acres treated with Disulfoton



Compiled by Dr. R.B. Head

Table 9. Phorate and alternative chemical usage on cotton[a]

Chemical	Treatment rate	No. treatments	Chemical price	Total treatment cost
	(lb ai/A)		($/lb ai)	($/A)
Granulars				
aldicarb	0.5	1	19.33	9.66
disulfoton	1.0	1	11.00	11.00
carbofuran	1.0	1	9.33	9.33
phorate	1.0	1	6.26	6.26
In-Furrow Sprays				
acephate	1.0	1	6.26	6.26
disulfoton	1.0	1	11.00	11.00
Seed Treatment				
acephate	0.05	1	6.26	0.31
Foliar Sprays				
acephate	0.33	2	6.26	7.31
dicrotophos	0.25	2	7.32	6.66
dimethoate	0.25	2	6.76	6.38
azinphosmethyl	0.25	2	11.04	8.52

[a]Source: NAPIAP Phorate Survey, 1990.

Chemical Alternatives for Pest Management

Foliar applications of insecticides to control thrips have a negative impact on the predators and parasites of other cotton pests, and thus contribute to pest outbreaks (Horn, 1988). The impact on predators and parasites is not as great when systemic granular insecticides, rather than foliar sprays, are used to control thrips. Seed and hopper-box treatment with acephate is another chemical alternative to phorate. When granular systemic insecticides are not applied, adequate control of thrips will require two to four applications of foliar insecticides (Table 10). In addition, foliar insecticides may have negative impacts on beneficial arthropods, thereby contributing to secondary pest outbreaks. Repeated applications of foliar insecticides may also intensify selection for resistance in both target and non-target pests. However, if the registrations of all granular insecticides are canceled, cotton producers will be forced to use foliar applications on a larger scale.

Non-Chemical Management Alternatives

Cotton is better able to tolerate thrips infestation when it is grown in an environment which promotes vigorous growth. Less than optimal environmental conditions, particularly air temperatures below 60 F (which are common during May in the northern portions of the southeast and mid-south), increase the importance of thrips management. Early-season growth of cotton is stimulated when the seedbed is well prepared and high quality seed is planted. A good disease management program is also important to ensure vigorous plant growth.

Rotation of cotton with other crops such as soybeans, corn, grains, sorghum and legumes improves plant health and vigor, and thus may increase resistance to insect pests. However, rotation is a viable strategy only when a producer has an excess of quality soils. In most cases, quality soils are limited, and cotton is planted in the same fields for decades.

Table 10. Chemical alternatives to granular insecticides for control of insect pests of cotton[a]

State	Chemical alternatives
Alabama	Foliar application of acephate, dicrotophos, dimethoate or methamidophos at 0.2 lb ai/acre.
Arizona	Emulsifiable concentrate formulations at planting.
Arkansas	Foliar application of dicrotophos or dimethoate (2-4 times).
California	Foliar application of acephate (3% increase) and parathion (7% increase).
Florida	Seed treatment and in-furrow treatment with acephate. Foliar application of acephate (3-5 times).
Georgia	Foliar application of dimethoate at 0.2 lb ai/acre.
Louisiana	Seed treatment and in-furrow treatment with acephate.
Mississippi	Foliar application of acephate at 0.33 lb ai/acre, dicrotophos at 0.25 lb ai/acre, or dimethoate at 0.25 lb ai/acre (2-4 times).
Missouri	Acephate would be the insecticide of choice.
New Mexico	Liquid formulations of carbofuran and disulfoton.
North Carolina	Foliar applications of dicrotophos at 0.25 ai/acre, phosphamidon at 0.25 ai/acre, dimethoate 0.1 lb ai/acre, or acephate at 0.25 lb ai/acre.
Oklahoma	Hopper box or foliar applications of acephate, dicrotophos, dimethoate, oxydemeton-methyl, or phosphamidon.
South Carolina	Seed treatment and foliar applications (1-2 times), or acephate in-furrow at 1.0 lb ai/acre.
Tennessee	Seed treatment with acephate. Foliar applications of acephate, azinphosmethyl, dicrotophos, or methamidophos. In-furrow sprays of acephate or disulfoton.
Texas	Seed treatment with acephate and foliar applications with acephate, dicrotophos, or dimethoate (2 times).

[a]Source: NAPIAP Phorate Survey, 1990.

Potential for Pest Resistance

The use of phorate increases the potential for pest resistance to organophosphate insecticides. However, the use of this chemical also reduces the potential for pest resistance to pyrethroid and carbamate insecticides.

Summary

Phorate is applied at planting to approximately 480,507 acres (4%) of cotton produced in the United States. All cotton producing states, with the exception of Tennessee, report phorate use on cotton. Of the granular chemicals applied by cotton producers, phorate is the second choice, accounting for 4% of total granular usage. The granular chemical alternatives to phorate include aldicarb, carbofuran, and disulfoton. The cancellation of phorate will lead to an increase in the average cost of insect control due to the higher prices of the chemical alternatives.

If all granular insecticides are canceled, the chemical alternatives for control of thrips would include acephate seed and hopper box treatments, acephate in-furrow application at planting, and foliar applications of acephate. However, these alternatives will increase production costs, have detrimental effects on beneficial arthropods, and increase the risk of drift to non-target areas. Good crop production practices can help reduce thrips damage, but often only increase tolerance to thrips without providing suppression of thrips.

Phorate Use on Peanut

(*Arachis hypogaea* L.) production in the United States ... regions: 1) the southeast (Georgia, Florida ...), 2) the southwest (... New Mexico), and 3) Virginia-Carolina (Virginia, North Carolina, South Carolina) ... statistics for states which ... is produced in the southeast ... value of $1 billion.

[illegible]

Maximum yields ... and good ... [illegible]

... for ... types of plants.

Registration Summary

... is registered for application in peanut ... application ... at planting ... systemic ... over the top of the row ... southern ... soil ...

Phorate Use on Peanut

Rick L. Brandenburg

Peanut (*Arachis hypogaea* L.) production in the United States is divided into three geographic regions: 1) the southeast (Georgia, Florida, Alabama), 2) the southwest (Texas, Oklahoma, New Mexico), and 3) Virginia-Carolina (Virginia, North Carolina, South Carolina). Production statistics for states which produce peanut are provided in Table 11. Peanut production is centered in the southeast, which accounts for approximately 1.5 million acres with a market value of $1 billion.

Table 11. United States peanut production, 1984-88[a]

State	Area planted	Production	Average yield	Value	Average market price
	(Acres)	(tons)	(lb/A)	(thousand $)	($/lb)
Alabama	219,200	276,474	2,539	148,667	.269
Florida	89,000	114,626	2,823	58,307	.254
Georgia	647,600	910,415	2,834	490,390	.269
New Mexico	13,100	15,968	2,438	9,852	.308
North Carolina	152,400	215,488	2,862	120,455	.279
Oklahoma	95,800	99,014	2,176	55,047	.278
South Carolina	13,200	16,228	2,497	8,329	.257
Texas	244,600	203,242	1,708	94,092	.231
Virginia	93,200	134,524	2,905	69,222	.257
Total	1,568,100	1,985,979		1,054,361	

[a]Source: USDA (1986, 1987, 1989).

Maximum yields are obtained when peanuts are grown on sandy soils with light to medium texture and good drainage (Pattee and Young, 1982). Peanuts are commonly rotated with a grass crop or cotton to aid in disease suppression. Irrigation is more frequently used in the southeast and southwest than in the Virginia-Carolina production region. The number of days required for maturity ranges from 100 days for Spanish and Valencia peanut types to 160 days for Virginia-types of plants.

Registration Summary

Phorate is labeled for application to peanuts at two specific plant growth stages: at-planting and at-pegging. Application at-planting is in the seed furrow at the rate of 7.3 oz per 1,000 ft of row for any row spacing (minimum 24-inch spacing), or at approximately 1 lb ai per acre in 36-inch rows. The at-planting application provides systemic control of thrips (primarily *Franklinella fusca* [Hinds]) and leafhoppers (*Empoasca fabae* [Narris]), but control of thrips is generally considered the most critical to maintaining adequate peanut yield. The at-pegging application is in a 12- to 16-inch band over the top of the row at the rate of 2 lb ai per acre (36-inch rows), then incorporated into the top layer of soil immediately after application. The at-pegging application provides control of southern corn rootworm (*Diabrotica undecimpunctata howardi* Barber) and leafhoppers.

Pest Infestation and Damage

Thrips are the most common target pest for at-plant applications of phorate to peanut. Yield loss from thrips infestation may reach 500 lb per acre in the Virginia-Carolina production region (Brandenburg, 1990). However, researchers in the southeast and southwest do not attribute significant yield loss to thrips damage (Smith, 1972; Tappan and Gorbet, 1981). The greater yield losses in the Virginia-Carolina production region may be due to the longer maturity period of Virginia-type peanuts which is exacerbated by early-season stunting by thrips. Producers in the Virginia-Carolina region cannot delay harvesting for long due to an increased risk of damage from frost. Management of thrips has become more important due to the spread of tomato spotted wilt virus, a disease that is transmitted by thrips. Large reductions in peanut yield have been attributed to tomato spotted wilt virus in the southeast and southwest production regions (French, 1989). Insecticides are useful in reducing the secondary spread of tomato spotted wilt virus (Weeks *et al.*, 1988).

At-pegging applications of insecticides to peanut are primarily aimed at controlling the southern corn rootworm The southern corn rootworm is a subterranean pest that feeds on peanut pegs and pods (Hunt and Baker, 1982). Infestation by southern corn rootworm is most serious when peanut is grown on soils with a high clay content, such as those found in Georgia, North Carolina, South Carolina and Virginia (Campbell and Emery, 1967). Southern corn rootworm is occasionally a problem in Alabama and Florida, but it is rarely observed in the states of the southwestern production region. Control of leafhoppers, which are not a primary peanut pest, is a secondary benefit of at-pegging application of insecticides.

Pest Management

Current Chemical Usage

The results of the National Agricultural Pesticide Impact Assessment Program (NAPIAP) pesticide use assessment survey indicate that phorate is used in all states producing peanut (Table 12). The most common use of phorate is as an at-plant in-furrow treatment for control of thrips at a rate of 1.0 lb ai/acre. At-planting applications are used on 8.7% of peanut acreage, and account for 92.6% of its total usage on peanut (Table 2). The remainder of phorate usage on peanut is in three states (Florida, North Carolina, Virginia) as an at-pegging application at a rate of 2.0 lb/acre (36-inch rows). Phorate is generally applied once per season, but in some instances may be applied both as an at-plant and at-pegging treatment. Application of phorate at-pegging is for control of southern corn rootworm in Virginia and North Carolina. Wireworms (Elateridae), lesser cornstalk borer (*Elasmopalpus lignosellus* [Zeller]), and cutworms (Noctuidae) are the target pests for at-pegging applications of insecticides in South Carolina, but phorate is not the product used. Florida uses an at-pegging treatment for control of leafhoppers, and is the only state to list foliar sprays as an alternative treatment.

Choice of chemical alternatives to phorate for thrips control on peanut are based on availability, relative efficacy, and convenience of usage. All alternatives are granular formulations applied at-plant in-furrow. Aldicarb is the preferred alternative to phorate for thrips control (Table 13). Disulfoton is also used as an alternative, but its current usage is significantly lower than the usage of phorate and aldicarb. Use of carbofuran as an at-plant in-furrow insecticide is not significant.

Acephate is applied as a foliar treatment for thrips, but foliar applications are a secondary option to at-plant application in all states except Oklahoma. Virginia uses foliar applications in addition to an at-plant treatment. The frequency of applications, number of applications, and application rate used for foliar treatments varies from state to state. If granular insecticides were no longer available, foliar alternatives would be widely used. However, there is concern that frequent use of foliar applications will increase the frequency of spider mite (*Tetranychus urticae* Koch) outbreaks.

Chlorpyrifos and fonofos are the two most commonly used chemicals for the control of southern corn rootworm (Table 14). Use of phorate, ethoprop, and carbofuran for control of southern corn rootworm accounts for a small portion of total chemical use.

Non-Chemical Management Alternatives

There are few non-chemical management alternatives available for peanut insect control. Natural biological control is important, but has not been well documented. However, should all granular chemicals be canceled for use on peanut, natural biological control would be reduced due to an increase in the use of foliar chemicals.

Thrips infestation can be reduced by planting later in the season, but late-planted peanut is more susceptible to frost damage before and during harvest. Crop rotation does not reduce infestation by thrips or southern corn rootworm since the patchwork of crops adjacent to peanut fields provides alternate hosts for these pests. Rotation with corn may actually increase damage to peanut caused by southern corn rootworm since the populations that infest peanut are the offspring of an earlier generation that infested corn. Southern corn rootworm infestation is greatest in moist soils, and for this reason damage is more likely in fields that are irrigated or have a high clay content. Southern corn rootworm infestation can be reduced by avoiding soils with a high clay content. However, the need to rotate production for the suppression of diseases may force producers to return to soils that have a high clay content.

A Virginia-type peanut grown in the Virginia-Carolina production region, 'NC 6', has excellent resistance to southern corn rootworm and some resistance to thrips, but its use is declining as varieties with better yield and quality are released by plant breeders. The use of NC 6 permits growers to reduce the at-planting application of insecticide by 50% for control of thrips and by 75% for control of southern corn rootworm.

Integrated Pest Management

Because southern corn rootworm is a subterranean pest, insecticides must be applied prior to infestation so that a protective barrier can be formed around peanut pegs and pods (Brandenburg, 1990). Integrated pest management (IPM) scouting procedures are not useful as a management alternative for southern corn rootworm control since rescue treatment is not available.

Integrated Pest Management methodologies are available for thrips control in peanut, however the efficacy and convenience of in-furrow insecticide use at-planting makes preventative control very attractive to producers. The thresholds for the use of foliar treatments are based on percent damaged leaflets or actual thrips abundance. These IPM techniques require time for scouting and additional trips across the field for foliar insecticide applications. In areas where tomato spotted wilt virus is severe, both preventative and foliar insecticide applications are used. Thrips infestation can also be reduced by delaying the date peanuts are planted, if regional weather patterns permit.

Potential for Pest Resistance

The potential for development of pest resistance is moderate for thrips and southern corn rootworm. Both pests utilize a number of hosts (both treated and untreated) during the season, thereby reducing the potential for the development of resistance to any one chemical. However, it should be noted that the potential for pest resistance is increased anytime an insect is exposed to fewer insecticides, even though the pest utilizes several host plants.

Summary

Phorate represents a small, but significant share of the at-plant insecticide market in peanut. It is efficacious and reasonable in cost. Chemical alternatives to phorate are effective, but dependance on a reduced number of chemicals for control of peanut pests may lead to a loss in their efficacy due to enhanced soil microbial degradation or a slight increase in pest resistance. This problem would be more serious should aldicarb also be restricted or canceled for use on peanut.

The difficulty of assessing the reduction of peanut yield and quality caused by thrips infestation is compounded by increasing problems with tomato spotted wilt virus, which is vectored by thrips. If tomato spotted wilt virus continues to spread, it will be paramount that an array of chemicals be available so that effective thrips management programs can be implemented by peanut producers. Foliar treatments are effective for the control of thrips, but their use creates additional operations for producers and may increase the likelihood of infestations by spider mites and other secondary pests. Many foliar treatment alternatives are available, but it is difficult to predict what would happen to the price and availability of these chemicals should all granular chemicals be canceled.

Phorate plays a relatively minor role in the management of southern corn rootworm infestations of peanut. However, cancellation of phorate would have a greater impact on the peanut industry should the registrations of the granular insecticide alternatives also be canceled.

The economic impact of restrictions which limit the use of pesticides on peanut may be greater on individual production areas than indicated by national statistics. Peanut and cotton production provide the backbone of the local economies of some production areas, and are fully responsible for farm solvency. A reduction in the profitability of peanut production would have severe effects on the local economies of these areas since alternative crops are not available.

Table 12. Usage of phorate on peanut, 1987-89[a]

State	At-plant application Rate	At-plant application Area[b] treated	At-plant application Total chemical used	At-pegging application Rate	At-pegging application Area treated	At-pegging application Total chemical used	Chemical used both applications
	(lb ai/A)	(%)	(lb ai/A/yr)	(lb ai/A)	(%)	(lb ai/A/yr)	(lb ai/A/yr)
Alabama	1	10	21,920	--	0	0	21,920
Florida	1	25	22,250	2	1	890	23,140
Georgia	0.8	10	48,570	--	0	0	48,570
North Carolina	1	16	24,384	2	0.1	304	24,688
Oklahoma	1	3	2,874	--	0	0	2,874
South Carolina	0.8	5	495	--	0	0	495
Texas	1	<1	1,000	--	0	0	1,000
Virginia	1	10	9,320	2	5	9,320	18,640
Total			130,813			10,514	141,327

[a]Source: NAPIAP Phorate Survey, 1990.
[b]See Table 11 for number of acres planted.

Table 13. Estimated alternative chemical use (no. acres) at-planting if phorate were no longer available for application to peanuts[a]

State	Aldicarb	Disulfoton	Carbofuran	Acephate	Carbaryl	Malathion
Alabama	131,520[b]	50,416	0	15,344	0	0
Florida	26,700	53,400	4,450	0	0	0
Georgia	420,940	129,520	0	259,040	0	0
North Carolina	129,540	15,240	1,524	6,096	0	0
Oklahoma	14,657	14,944	0	15,807	5,221	2,080
South Carolina	12,540	660	0	0	0	0
Texas	0	0	0	0	0	0
Virginia	83,880	9,320	0	0	0	0
Total	819,777	273,500	5,974	296,287	5,221	2,080

[a]Source: NAPIAP Phorate Survey, 1990.
[b]Total number acres treated with alternative chemical.

Table 14. Estimated alternative chemical use (no. acres) at-pegging if phorate were no longer available for application to peanuts[a]

State	Chlorpyrifos	Fonofos	Ethoprop	Carbofuran	Methomyl	Carbaryl
Alabama	2,192[b]	1,320	0	0	0	0
Florida	5,340	445	0	0	445	445
Georgia	259,040	64,760	0	0	0	0
North Carolina	64,008	10,668	3,048	0	0	0
Oklahoma	0	0	0	0	0	0
South Carolina	6,600	0	0	0	0	0
Texas	0	0	0	0	0	0
Virginia	27,960	4,660	4,660	4,660	0	0
Total	365,140	81,853	7,708	4,660	445	445

[a]Source: NAPIAP Phorate Survey, 1990.
[b]Total number acres treated with alternative chemical.

Phorate Use on Potato

Jeffrey A. Wyman

Potato (*Solanum tuberosum* L.) is grown commercially on over 1.2 million acres in the United States. Annual production of potato ranged from 334 to 404 million cwt for 1983-89, with an annual average of 368.3 million cwt (USDA, 1990). Potatoes are produced commercially in 37 states, but 88% of total United States production occurs in 11 states. Potato production is concentrated in the Pacific Northwest (Idaho, Washington, and Oregon), the north central region (Michigan, Wisconsin, and the Red River Valley region of North Dakota and Minnesota), and in Colorado, Maine, California, and Florida.

The market value of the potato crop ranged from $1.6 to $2.1 billion for 1983-88. The fall harvest of potatoes accounts for 85% of total production. Potatoes are also harvested in the spring (southern states), summer (throughout the United States), and the winter (California and Florida). The price of potatoes is linked to local and national demand, tuber size, tuber quality, and the time of harvest. Prices are inversely related to supply, with average prices ranging from $3 to $8 per cwt over the past decade (USDA, 1989). Potatoes harvested in the spring and early summer are usually the most valuable. Market price is significantly reduced by pest damage and environmental stress, which adversely affect storage and processing qualities.

Registration Summary

Phorate is labeled for use on potato for control of aphids (Aphididae), leafhoppers (Cicadellidae), leaf miners (Agromyzidae), psyllids (Psyllidae), wireworms (Elateridae), fleabeetles (Chrysomelidae), and Colorado potato beetle (*Leptinotarsa decimlineata* Say). Phorate is applied as a soil treatment in the furrow at 2.0 lb ai/A on sandy soils and 3.0 lb ai/A on clay soils. Some state registrations (24c) permit use of phorate as a layby treatment at plant emergence.

Pest Infestation and Damage

The colorado potato beetle is the most destructive pest of potato in the eastern and north central production regions. Adult and larval feeding reduces both yield and tuber size, particularly when plants are defoliated early in the growing season. Yield reductions vary throughout the potato production areas. In the eastern states, complete crop failure may result from early season feeding. In the north-central production region, yield reductions range from 10% to 50% after first generation feeding and from 50% to 80% after first and second generation feeding (Longridge *et al.*, 1989).

The potato leafhopper (*Empoasca fabae* Harris) is a serious pest of potato in the north central production region where damaging infestations occur annually. Infestation by potato leafhopper is sporadic in the eastern and northeastern production regions and never occurs in the northwestern and Pacific regions. Potato leafhopper infestation reduces potato yields by 30% to 60% in the midwestern states if insecticides are not applied (Longridge *et al.*, 1989).

Several species of aphids are pests on potato, including the green peach aphid (*Myzus persicae* Sulzer), the potato aphid (*Macrosiphum euphorbiae* Thomas), the foxglove aphid

(*Acrythosiphon solani* Kaltenbach), and the buckthorn aphid (*Aphis nasturtii* Kaltenbach). Aphids are vectors of virus diseases of potato, such as potato leafroll and potato virus Y. Prevention of virus transmission by these vectors is critical to potato seed production, since the use of infected seed will result in dramatically reduced tuber yields in subsequent years (Bauernfeind, 1977). With the exception of potato leafroll virus, infection of current season potato with a virus does not normally reduce yield. Potato leafroll virus may cause net necrosis in susceptible cultivars such as 'Russet Burbank' and results in rejection by potato processors if damage exceeds 6% (W. Cranshaw, Colorado State University, personal communication). Seed potatoes are produced under strict sanitation conditions to reduce incidence of disease and enable certification as seed stock for subsequent plantings. Since extremely low thresholds for aphids in seed potatoes are necessary to keep virus transmission at acceptable levels, systemic control of aphids is very important.

Several species of wireworm cause severe damage to potato by burrowing into tubers. Several years are required to complete the life cycle of wireworms, thus infestation of potato originates in preceding crops or fallow periods.

Pest Management

Current Chemical Usage

The results of the National Pesticide Impact Assessment Program (NAPIAP) pesticide use assessment survey are presented in Table 15. Responses to the NAPIAP survey were received from 22 states, accounting for more than 90% of United States potato production. The voluntary withdrawal of aldicarb from all states in 1989 significantly altered pesticide use patterns on potato. If aldicarb were still available for use on potato, the impact of the loss of phorate on potato production would be lessened considerably.

<u>Northwest Region</u>: This is a geographically distinct region that represents 41% of United States potato production. Primary pests are aphids and wireworms. Colorado potato beetle is increasing in importance, but resistance to insecticides remains relatively low. Phorate is used extensively for aphid and wireworm control, and for Colorado potato beetle suppression. If phorate were no longer available for use on potato, producers would use disulfoton for aphid control and ethoprop for wireworm control. Several negative impacts would be associated with the use of these alternative chemicals:

- The switch to ethoprop would add approximately $10 per acre to the cost of wireworm control and the added benefit of systemic control of other insects now provided by phorate would be lost.

- The switch to disulfoton would provide effective aphid control, but early season suppression of Colorado potato beetle would be lost. Increased infestation by Colorado potato beetle would necessitate 1-2 additional foliar applications of an insecticide (probably a pyrethroid), increasing production costs by $6-10 per acre (H. Homan, University of Idaho, personal communication).

- Greater use of foliar sprays would increase selection pressure on Colorado potato beetle and aphids, resulting in a more rapid development of pest resistance (Radcliff and Watrin, 1986). The more rapid development of pest resistance would further add to control costs.

[illegible] and the bacteria [illegible] ant diseases of cereals [illegible] ous transmission by these ve[illegible] is critical to potato s[illegible] [illegible] will result in dramatically reduced [illegible] With the exception of [illegible] does not normally reduce yield [illegible] such as Russet Burbank [illegible] (W. Cranshaw, Colorado State [illegible]) [illegible] reduced under most conditions [illegible] in seed potatoes [illegible] control of aphids is very [illegible].

[illegible] species of [illegible] cause severe [illegible] are [illegible] common [illegible] preceding crops or fallow periods.

Pest Status [illegible]

[illegible] of the National [illegible] presented in Table [illegible] 1993 [illegible] production would be [illegible].

[illegible] Region. This is a geographically distinct region [illegible] production. Primary pests are [illegible] but resistance to [illegible] and wireworm control [illegible] available for [illegible] for wireworm control [illegible] alternatives [illegible].

[illegible] would add approximately [illegible] control of [illegible].

[illegible] would provide effective aphid control, but [illegible] potato [illegible] increased [illegible] 1-2 additional [illegible] applications [illegible] production costs by [illegible] per acre [illegible].

[illegible] control [illegible] control of [illegible] would [illegible] add to control costs.

- The total increase in the cost of production is estimated to be $25 per acre (H. Homan, University of Idaho, personal communication).

North-Central Region: This is a diverse region encompassing the Red River Valley (North Dakota, Minnesota), Wisconsin, and Michigan, which accounts for 26% of United States potato production. Key pests are potato leafhopper, Colorado potato beetle and aphids. Control failures are becoming more common due to the development of pesticide resistance among Colorado potato beetle populations (Graphius *et al.*, 1988). Phorate is applied to 20-30% of the acreage treated with a systemic insecticide in the north-central production region. If phorate were canceled, producers would use disulfoton for control of aphid and potato leafhopper, and carbofuran for control of Colorado potato beetle if the carbofuran label is retained. Several negative impacts would result from this change:

- Switching to disulfoton would reduce Colorado potato beetle suppression. Foliar applications of insecticides would be required to obtain adequate control, adding $10-15 per acre to production costs (J. Wyman, University of Wisconsin, unpublished data).

- Additional foliar sprays would increase the already serious resistance problem with Colorado potato beetle and aphids. This would result in the need to use more expensive alternative chemicals, at an anticipated cost of $5-6 per acre.

- Increased use of carbofuran for control of Colorado potato beetle would increase production costs by approximately $5 per acre. In addition, there would be greater risks to birds and groundwater supplies. Carbofuran is currently under Special Review and the manufacturer has proposed the removal of potato from the label.

- The total increase in the cost of production is estimated to be $15-25 per acre, and would be greater in states where the development of pest resistance is more serious.

West-Central Region: This is a geographically distinct region with production centered in Colorado. The primary pests in this region are the potato psyllid, aphid, and (increasingly) Colorado potato beetle. Insect problems in this region are generally less severe than those of other production regions. Phorate usage is low in this region and, with the exception of Montana, yield reductions are not anticipated should phorate be canceled.

Pacific Coast Region: Only California has significant potato acreage in this region. The primary pests in this region are aphids. Because phorate usage is low in California, no impact on potato yield is anticipated should its use be canceled.

Northeast Region: This is a multistate region dominated by Maine. The primary pests in the region are Colorado potato beetle and aphid. Colorado potato beetle is highly resistant to most registered insecticides, including phorate. The cancellation of phorate would have a negligible impact on potato production because it does not control resistant Colorado potato beetle. Phorate usage is significant only in Delaware, where it is used to control wireworm. The cancellation of phorate would have a small overall impact on potato production in the northeast region.

Southeast Region: This is a geographically diverse region. Each state in the region has intensively farmed areas, each with distinct pest problems. In Florida, phorate is used on 5,000 acres for wireworm control. Because alternative chemicals are not available, the cancellation of phorate would result in severe yield losses. In North Carolina, phorate use is extensive, but could be replaced by disulfoton. The already high level of Colorado potato beetle resistance in

[illegible] university [illegible] person [illegible]

[illegible] Region. This [illegible] in [illegible] bon. Key pests in potato [illegible] from [illegible] do potato beetle [illegible] s treated with a systemic [illegible] [illegible], predators [illegible] control of Colorado [illegible] this can [illegible] impacts would [illegible]

[illegible] would [illegible] Colorado [illegible] to products [illegible] costs [illegible]

[illegible] foliar sprays would [illegible] Colorado potato beetle [illegible] [illegible] chemicals, at an [illegible]

[illegible] use of carbofuran for control [illegible] cost by approximately [illegible] [illegible] and groundwater supplies [illegible] [illegible] has proposed [illegible] removal [illegible]

[illegible] increase in the cost of [illegible] [illegible] in states where the [illegible]

[illegible] Region. This is a geographically [illegible] primary pests in this region are the [illegible] potato beetle. Insect problems in this [illegible] [illegible] regions. Phorate usage is low in this region [illegible] reductions are not anticipated [illegible]

[illegible] Region. Only California has significant [illegible] this region are aphids. Because phorate [illegible] is anticipated [illegible] its use [illegible] cancelled.

[illegible] Region. This is a multistate region dominated by Maine [illegible] Colorado potato beetle and [illegible] Colorado potato beetle [illegible] insecticides, including phorate. The cancellation of [illegible] potato production because it does not control [illegible] [illegible] is [illegible] only in Delaware, where it is used [illegible] control [illegible] [illegible] of phorate would have a small overall impact on potato production [illegible]

[illegible] This is a [illegible] diverse region. Each state [illegible] [illegible], each with distinct pest problems. In [illegible] [illegible] Because alternative chemicals are not available [illegible] [illegible] severe yield losses. In North Carolina, phorate [illegible] the [illegible] of Colorado potato beetle [illegible]

that state would increase if phorate were not available, but it is not anticipated that yield would be reduced. The overall impact of phorate cancellation on potato production in the southeast would be small, but would be severe in localized areas.

Chemical Alternatives for Pest Management

Colorado Potato Beetle: Although phorate is not as effective as systemic carbamate alternatives (aldicarb, carbofuran, oxamyl), it does provide early-season suppression of phorate-susceptible populations. Suppression with phorate reduces the number of foliar applications necessary to control Colorado potato beetle, thereby reducing the potential for development of pest resistance to chemical alternatives, such as the pyrethroids. Aldicarb provides the most effective control, but toxicological and environmental concerns resulted in a voluntary withdrawal from all states in 1989. The continuing availability of aldicarb is an important consideration in the impact assessment of phorate. If aldicarb were available for use on potato, the cancellation of phorate would have a small impact on the management of Colorado potato beetle infestations. Carbofuran and oxamyl are effective alternatives in control of susceptible Colorado potato beetle populations. However, carbofuran is currently in the Special Review process and oxamyl has a high potential for leaching, thus the future use of these alternatives is questionable. The soil-applied systemic organophosphate disulfoton does not generally provide economic suppression of Colorado potato beetle. Chemicals applied as foliar sprays provide the only alternative for Colorado potato beetle management should systemic insecticides no longer be available for use on potato. A wide range of chemicals applied as foliar sprays is available for control of susceptible Colorado potato beetle populations. However, extensive use of these chemicals rapidly leads to the development of pest resistance.

Potato Leafhopper: Phorate is extremely effective in potato leafhopper control with systemic activity providing protection for 8-10 weeks (Longridge *et al.*, 1989). Equivalent systemic control of potato leafhopper is provided by disulfoton or the carbamate systemics (aldicarb, carbofuran). Systemic control of potato leafhopper reduces the need for foliar insecticides, to which other potato insect pests are likely to develop resistance. A wide range of foliar insecticides is available which provide good potato leafhopper control.

Aphids: For the production of potato seed, phorate provides excellent aphid control with protection at or below threshold levels for 4 weeks in the northwest and for 8-10 weeks in the north-central and eastern production regions. Lower levels of protection are required in the production of table stock and processing potatoes. Equivalent systemic control is provided by disulfoton and aldicarb. Good control is provided by the foliar chemicals endosulfan and methamidophos, but their repeated use could lead to the development of pest resistance. Aphids rapidly develop resistance when exposed to repeated foliar sprays. Early-season applications of systemic chemicals are important because they reduce the need for foliar applications.

Wireworms: Phorate provides good control or suppression of wireworms. The alternative systemic insecticides (disulfoton, carbofuran, and aldicarb) do not provide effective wireworm control. Broadcast applications of soil-applied insecticides such as fonofos and ethoprop provide adequate control of wireworm. However, these chemicals do not provide systemic protection against other potato pests and they do significantly increase production costs.

[illegible] introduce if [illegible] were [illegible] table, [illegible] The overall impact [illegible] [illegible] but would be severe in localized areas.

[illegible] Alternatives for Pest Management

[illegible] Beetle. Although [illegible] carbofuran, [illegible] combination with [illegible] potato [illegible] chemical alternatives, [illegible] biological [illegible] stated in 1982 [illegible] the insect [illegible] of [illegible] Carbaryl, and [illegible] populations, however, [illegible] has a high potential of [illegible] applied systemic [illegible] [illegible] of [illegible] for Colorado [illegible] be available for [illegible] for control of [illegible] these chemicals [illegible]

[illegible] effectively [illegible] for 8-10 weeks (i.e. [illegible] insecticide [illegible] the [illegible] control of potato leafhopper [illegible] pests are likely to [illegible] which provide good potato [illegible]

[illegible] of the [illegible] of potato [illegible] below threshold levels for 4 weeks [illegible] production regions. Lower levels [illegible] for and processing potatoes. [illegible] Good control is provided by the [illegible] [illegible] species [illegible] develop [illegible] exposed [illegible] chemicals are important [illegible]

[illegible] good control of [illegible] of wireworm [illegible] (disulfoton, carbofuran, and aldicarb) do not [illegible] of soil [illegible] such as fonofos and ethoprop [illegible] of wireworm. However, these chemicals do not [illegible] potato pests and [illegible]

Non-Chemical Management Alternatives

Non-chemical alternatives can be used to reduce Colorado potato beetle population levels, but generally are not sufficient to provide economic control. Crop rotation delays and reduces the impact of Colorado potato beetle infestations (Lashomb and Ng, 1984). Biological control alternatives using parasites and predators for Colorado potato beetle control in potatoes are being developed but are not commercially available. New strains of *Bacillus thuringiensis* Berliner provide effective Colorado potato beetle control when they are directed against early instar larvae (Ferro and Gelerntner, 1989). The use of *B. thuringiensis* does not disrupt natural predation, which is important in some production areas.

No effective non-chemical alternatives exist for potato leafhopper control.

Aphid populations are controlled by a broad range of naturally occurring parasites, predators, and pathogens. However, these biological controls are rarely sufficient to reduce aphid populations to the extremely low levels required for potato seed production. Spatial or temporal isolation of seed potatoes is effective in delaying aphid infestations, but chemical control is required when infestation does occur. Two states (Idaho and Maine) have attempted to eliminate alternate hosts of aphids in an effort to reduce population levels (Storch, 1981).

No effective biological controls exist for wireworms in potatoes. Crop rotations which do not include the host plants preferred by adult beetles for oviposition is one management alternative. However, the long life-cycle of wireworms reduces the effectiveness of crop rotation for the management of wireworm populations.

Integrated Pest Management

Integrated pest management strategies based on crop scouting, insect prediction, and economic thresholds are used extensively in potato production. A computer program for potato pest management and production has been developed for the midwest production region (Stevenson *et al.*, 1990). This program, called *Potato Crop Management*, is credited with saving midwest potato producers $800,000 per year on the 40,000 acres of potatoes where it has been used.

Potential for Pest Resistance

Insecticide resistance is a critical factor in the management of Colorado potato beetle populations. High levels of insecticide resistance among Colorado potato beetle populations in the northeast is a severe limitation to potato production (Forgash, 1985; Ferro, 1985). Insecticide resistance has recently been reported in Pennsylvania, North Carolina, Michigan, and Minnesota (Radcliff and Watrin, 1986; Graffius, 1988). It is highly probable that resistance will also develop in the north-central and northwestern production regions. Phorate does not provide effective control of insecticide resistant Colorado potato beetle, but it can play an important role in the management of resistance in susceptible populations and populations which have developed a low level of resistance (Johnson and Sandvol, 1986).

Insecticide resistance is also extremely important in aphid populations. Because aphids develop resistance to foliar insecticides very rapidly, systemic insecticides such as phorate and disulfoton are important in aphid resistance management programs.

[illegible] Management Alternatives

[illegible]-chemical alternatives can be used to [illegible] generally are necessary [illegible] plan to prevent [illegible] pact of Colorado potato beetle infestations [illegible] using pesticides and pesticide [illegible] utilize [illegible] has not [illegible] provide effective [illegible] to be used (Ferro and Gelernter, 1989) [illegible], which is important in [illegible]

[illegible] Non-chemical [illegible]

[illegible] pest populations [illegible] pathogens. [illegible] is the extremely low level [illegible] on a seed [illegible] alone is one [illegible] in infestation or [illegible] alternate hosts [illegible]

[illegible]ffective biological controls [illegible] the host plants preferred [illegible], the long life-cycle o[illegible] of wireworm popul[illegible]

[illegible] Pest Management

[illegible]grated pest management [illegible] insecticides are used [illegible] management and production [illegible] et al., 1989). [illegible] midwest potato producers [illegible] per [illegible] been used.

[illegible] resistance is a [illegible] High levels of insecticide resistance [illegible] Colorado potato [illegible] severe limitation [illegible] potato production [illegible] resistance has recently been reported [illegible] (Roush and Miller, 1986; Grafius, 1986; [illegible]) [illegible] the Province of the north-central and northeastern production regions [illegible] effective control of insecticide resistant Colorado potato beetle [illegible] role in the management of resistance in susceptible populations [illegible] have developed a low level of resistance (Johnson and Sandvol, 1985).

[illegible] also extremely important in areas [illegible] resistance to foliar insecticides very rapidly [illegible] are important in spud [illegible] management programs.

Summary

Phorate is used extensively in two major potato production regions, the northwest and the north-central. In these regions, cancellation of phorate would significantly increase production costs and would increase the development of insecticide resistance among populations of two key insect pests: the Colorado potato beetle and aphid. Phorate is not widely used in the other production regions, generally because it does not control resistant populations of Colorado potato beetle. In those production regions, the cancellation of phorate would result in localized negative impacts, primarily due to greater difficulties in controlling wireworm populations.

The development of high levels of insecticide resistance can have a severe impact the potato industry. Potato production in the eastern region has already been adversely affected by an increase in pest resistance to insecticides. Phorate is important in the management of pest resistance, particularly when only low levels of resistance have developed in pest populations.

In the major production regions, the cancellation of phorate would lead to a significant increase in the application of foliar insecticides. A greater reliance on foliar application of insecticides would increase the potential for pesticide drift and toxicity to non-target organisms. On balance, the removal of phorate would result in negative environmental and economic impacts.

Table 15. Phorate and alternative chemical usage in United States potato production[a]

State & key pests	Chemical	--- Area treated if: --- Phorate available	Phorate unavailable	Treatment rate	Total treatment cost	No. treatments	Change in yield	Overall impact
		(%)	(%)	(lb ai/A)	($/A)		(%)	
Northwest Region								
Idaho (353,000 acres @290 cwt/A, $5.40/cwt)								
aphids	phorate	80	--	3.00	25	1	--	Disulfoton increase for aphid control. Ethoprop + fonofos for wireworm. Additional foliar sprays for CPB could incr. resist. in CPB and aphids. Use of esfenvalerate would incr. production costs by $25/acre.
wireworms	disulfoton	15	50	3.00	24	1	0	
Col. pot. beetle	ethoprop	25	50	3.00	33	1	0	
	fonofos	10	15	3.00	54	1	0	
	carbofuran	1	1	3.00	28	1	0	
	esfenvalerate	0	50	0.03	6	1-2	0	
Washington (119,830 acres @545 cwt/A $4.50/cwt)								
aphids	phorate	66	--	3.00	25	1	--	Same as Idaho
Col. pot. beetle	disulfoton	22	88	3.00	24	1	0	
wireworms	ethoprop	7	30	3.00	33	1	0	
	carbofuran	1	5	3.00	28	1	0	
	esfenvalerate	0	50	0.03	6	1-2	0	
Oregon (54,000 acres @450 cwt/A, $4.95/cwt)								
aphids	phorate	44	--	3.00	25	1	--	Same as Idaho
Col. pot. beetle	disulfoton	5	20	3.00	24	1	0	
wireworms	ethoprop	41	50	3.00	33	1	0	
	fensulfothion	4	10	4.00	32	1	0	
	esfenvalerate	0	50	0.03	6	1-2	0	

Table 15 *(continued)*

State & key pests	Chemical	--- Area treated if: --- Phorate available	Phorate unavailable	Treatment rate	Total treatment cost	No. treatments	Change in yield	Overall impact
		(%)	(%)	(lb ai/A)	($/A)		(%)	
North-Central Region								
North Dakota (137,000 acres @ 110 cwt/A, $6.35/cwt)								
Col. pot. beetle leafhopper	phorate	26	--	3.00	19	1	--	Disulfoton increase for aphids & PLH. Carbofuran inc. for CPB. Added foliar sprays needed for CPB. Inc. pest resist. Overall cost inc would be 2 sprays or $10-15/A.
	disulfoton	6	35	3.00	24	1	0	
	carbofuran	2	10	3.00	28	1	0	
	endosulfan	13	30	1.00	8	1	0	
	esfenvalerate	72	90	0.03	6	1-2	0	
	permethrin	0	10	0.10	6	1	0	
	methamidofos	2	2	0.75	13	1	0	
Minnesota (72,300 acres @ 218 cwt/A, $6.20/cwt)								
potato leafhopper Col. pot. beetle aphids	phorate	20	--	3.00	19	1	--	As for N.D. with more PLH and CPB pressure. Inc. resistance. Cost inc: $10-15/A.
	disulfoton	7	35	3.00	24	1	0	
	carbofuran	22	30	3.00	28	1	0	
	endosulfan	24	35	1.00	8	1-2	0	
	esfenvalerate	101	120	0.03	6	1-2	0	
	permethrin	12	20	0.10	6	1	0	
	methamidofos	1	5	0.75	13	1	0	
Wisconsin (62,000 acres @ 345 cwt/A, $6.40/cwt)								
potato leafhopper Col. pot. beetle aphids	phorate	30	--	3.00	19	1	--	Disulfoton incr. for PLH & aphid. Carbofuran inc. for CPB; pot. for leaching. Ethoprop for soil insects. Inc. pest resist. Cost inc: $10-15/A.
	disulfoton	22	50	3.00	24	1	0	
	carbofuran	1	10	3.00	26	1	0	
	endosulfan	5	20	1.00	8	1	0	
	esfenvalerate	75	90	0.03	6	2	0	
	permethrin	25	50	0.10	6	2	0	
	methamidofos	15	20	0.75	13	2	0	
	ethoprop	1	5	3.00	33	1	0	
Michigan (40,000 acres @ 230 cwt/A, $7.55/cwt)								
Col. pot. beetle potato leafhopper aphids fleabeetle	phorate	24	--	3.00	19	1	--	Disul./carbofuran inc. for CPB & PLH. Foliar sprays doubled.; 10% yield loss. Inc. env. problems. Spray costs doubled.
	disulfoton	5	10	3.00	29	1	-10	
	carbofuran	5	10	3.00	28	1	-10	
	phosmet	40	40	0.50	5	3-5	-10	
	endosulfan	30	50	1.00	9	2-4	-10	
	carbaryl	10	60	1.00	6	2-3	-10	
	dimethoate	10	40	0.50	3	1-2	-10	
	guthion	60	60	0.50	5	3-5	-10	

Table 15 (*continued*)

State & key pests	Chemical	--- Area treated if: --- Phorate available	Phorate unavailable	Treatment rate	Total treatment cost	No. treatments	Change in yield	Overall impact
		(%)	(%)	(lb ai/A)	($/A)		(%)	
North-Central Region (*continued*)								
Ohio (9,600 acres @ 185 cwt/A, $6,90/cwt)								
Col. pot. beetle	phorate	80	--	3.00	19	1	--	Incr. in disulfoton/ carbofuran for CPB. Fonofos incr. for wireworm, but still 100% loss in some fields. Inc. use foliar sprays.
wireworms	disulfoton	5	40	3.00	24	1	-10	
fleabeetle	carbofuran	5	25	3.00	26	1	-10	
	fonofos	5	25	3.00	54	1	-10	
	esfenvalerate	0	50	0.03	6	1-2	-10	
	no treatment	5	10	0.00	0	---	-10	
Missouri (4,333 acres @ 200 cwt/A, $6.50/cwt)								
Col. pot. beetle	phorate	60	--	2.00	20	1	--	Switch from phorate to carbofuran if avail. Incr. use of foliar sprays if no carbofuran.
wireworms	carbofuran	30	90	3.25	20	1	+8	
	esfenvalerate	0	90	0.03	6	1-2	0	
West Central Region								
Colorado (65,840 acres @ 333 cwt/A, $4.51)								
potato psyllid	phorate	1	--	3.00	19	1	--	No impact.
Col. pot. beetle	disulfoton	2	2	3.00	24	1	0	
	permethrin	13	13	0.10	6	1-2	0	
	esfenvalerate	74	74	0.03	6	1-2	0	
Utah (6,540 acres @ 252 cwt/A, $4.90/cwt)								
Col. pot. beetle	phorate	5	--	3.00	19	1	--	No impact other than a small inc. in foliar sprays.
armyworms	guthion	8	10		5	1	0	
cutworms								
Montana (5,875 acres @ 285 cwt/A, $7.20/cwt)								
wireworms	phorate	20	--	3.00	19	1	--	Incr. use of foliar sprays.
aphids	disulfoton	22	40	0.75	9	3	-10	
leafhoppers								
psyllids	methamidofos	20	40	1.00	9	3	-10	10% yield reduction.
Wyoming (3,600 acres @ 205 cwt/A, $5.80/cwt)								
aphids	phorate	0	0				--	No impact.
Col. pot. beetle	disulfoton	37	37	0.4-1.0	5-9	1	0	
	fenvalerate	25	25	0.10	6	1-2	0	
	dimenthoate	17	17	0.50	3	1	0	
	parathion	8	8	0.50	5	1	0	
Pacific Coast Region								
California (54,000 acres @ 380 cwt/A, $8.35/cwt)								
aphids	phorate	3	--	2.80	20	1	--	No impact.
	disulfoton	1	2	2.00	17	1	0	
	methamidofos	56	56	0.87	9	1-3	0	
	parathion	1	1	0.50	5	1	0	

Table 15 *(continued)*

State & key pests	Chemical	--- Area treated if: --- Phorate available	Phorate unavailable	Treatment rate	treatment cost	No. treatments	Change in yield	Overall impact
		(%)	(%)	(lb ai/A)	($/A)		(%)	
Northeast Region								
Maine (80,000 acres @ 275 cwt/A, $4.78/cwt)								
aphids	phorate	5	--	2.00	15	1	--	Small shift to disulfoton may require 1-2 add. foliar appl. for CPB. Cost inc: $10/A on 5% of acreage.
leafhopper	disulfoton	30	38	2.25-3.0	20-21	1	0	
Col. pot. beetle	permethrin	38	38	0.10	7	2-3	0	
wireworms	esfenvalerate	38	38	0.038	8	2-3	0	
	methamidofos	98	98	0.75	12-19	2-3	0	
	endosulfan	12	12	0.75	9	2-3	0	
	ethoprop	2	2	3.00	39	1	0	
	fonofos	1	1	4.00	44	1	0	
New York (28,800 acres @ 230 cwt/A, $8.50/cwt)								
potato leafhopper	phorate	30	--	3.00	20	1	--	If switch to disulfoton will require 1-2 additional foliar sprays.
Col. pot. beetle	disulfoton	9	39	3.00	24	1	0	
	permethrin	30	30	0.10	6	1-2	0	
	esfenvalerate	35	35	0.03	6	1-2	0	
	methamidofos	90	90	0.50	6	1-2	0	
	parathion	30	30	0.50	3	3	0	
Delaware (8,000 acres @ 160 cwt/A, $6.50/cwt)								
potato leafhopper	phorate	3	--	2.00	13	1	--	Inc. carbofuran and ethoprop. Inc. loss from wireworm. Cost incr. $10-12/A.
wireworms	carbofuran	75	100	3.00	26	1	0	
fleabeetle	ethoprop	2	10	3.00	21	1	-5	
New Jersey (5,000 185 cwt/A, $6.50/cwt)								
Col. pot. beetle	phorate	2	--	3.00	20	1	--	Small impact: phorate not effective on CPB.
potato leafhopper	carbofuran	70	70	3.00	26	1	0	
fleabeetle	endosulfan	80	80	1.00	8	1-2	0	
	oxamyl	70	70	1.00	12	1-2	0	
	guthion	50	50	0.50	5	1-2	0	
	permethrin	40	40	0.20	10	1-2	0	
	esfenvalerate	45	45	0.05	10	1-2	0	
	rotenone	20	20	0.25	NI	2	0	
Maryland (1,800 acres @ 225 cwt/A, $6/cwt)								
Col. pot. beetle	carbofuran	10	10	2-3.00	11-62	1	0	No phorate used.
	aldicarb	80	80	2-3.00	45-60	1	0	

Table 15 (*continued*)

State & key pests	Chemical	--- Area treated if: --- Phorate available	Phorate unavailable	Treatment rate	Total treatment cost	No. treatments	Change in yield	Overall impact
		(%)	(%)	(lb ai/A)	($/A)		(%)	
Southeast Region								
Florida (37,220 acres @ 195 cwt/A, $10.97/cwt)								
wireworms	phorate	14	--	3.60	40	1	Loss	Yield losses of up to 100%.
	(no alternatives)	--	--					
North Carolina (16,025 acres @ 156 cwt/A, $5.65/cwt)								
Col. pot. beetle	phorate	60	--	2-3.00	20	1	--	Switch to disulfoton and incr. in resist. would result in more foliar sprays.
	disulfoton	30	70	2-3.00	24	1	0	
	oxamyl	20	20	0.50	12	3	+20	
	B.T.	5	5	4-6.00 qt	15	3	-5	
	rotation	20	40	--	--	--	+60	
Louisiana (1,000 acres @ 150 cwt/A, $6/cwt)								
Col. pot. beetle	phorate	25	--	2-3.00	14-20	1	--	Incr. disulfoton and incr. use of foliar sprays with cost incr. of $7/Acre on 25% acreage.
	disulfoton	20	40	2.00	14	1	0	
	permethrin	25	50	0.10	7	2	0	
	no treatment	25	25	--	--	--	0	

[a]Source: NAPIAP Phorate Survey, 1990.

Phorate and Terbufos Use on Sorghum

Allen E. Knutson

Granular formulations of phorate and terbufos are applied to sorghum (*Sorghum bicolor* [L.] Moench) to control above ground and soil dwelling insect pests. These insecticides provide systemic protection from infestation by greenbug (*Schizaphis graminum* [Rondani]), corn leaf aphid (*Rhopalosiphum maidis* [Fitch]), yellow sugarcane aphid (*Sipha flava* [Forbes]), and chinch bug (*Blissus leucopterus leucopterus* [Say]). Terbufos is also labeled for control of the major sorghum soil dwelling pests: southern corn rootworm (*Diabrotica undecimpuncta howardi* [Barber]), wireworms (*Eleodes* spp. and *Conoderus* spp.), white grubs (*Phyllophaga* spp.), and plant parasitic nematodes.

Registration Summary

Phorate is registered for soil and foliar application. Terbufos is only registered for soil application. In-furrow applications are not recommended for either of these insecticides due to the potential for increased stand losses due to phytotoxicity. The recommended method of application of phorate and terbufos depends upon the target pest. Terbufos may be applied only once a year. Phorate may be applied at planting and again after plant emergence if necessary.

The recommended application method for control of greenbug and corn leaf aphid is in a 5- to 7-inch band at the rate of 1 lb ai/A (constant at all row spacings) over the row at planting or drilled into the soil directly below or to the side of the seed. This application can be made preplant when seed beds are formed (terbufos only) or at planting.

Phorate can be applied to the base of plants for chinch bug control during cultivation so as to cover the granules with soil. Phorate is also labeled for broadcast application into plant whorls for control of greenbug and Banks grass mite (*Oligonychus pratensis* [Banks]). However, the 1991 phorate labels will no longer permit broadcast application to sorghum by air or ground equipment.

Terbufos is applied in a row band for control of southern corn rootworms wireworms, white grubs, and nematodes. Terbufos is also registered (supplemental label) for a modified in-furrow application for early season greenbug control in Texas, Louisiana, Georgia, Alabama, Mississippi and Florida. Because terbufos is placed at the base of the plant during the modified in-furrow application, it also provides coincidental control of chinch bugs.

Pest Infestation and Damage

The economic importance and control of sorghum pests were reviewed by Young and Teetes (1977). Greenbug is the most important pest throughout the United States sorghum production region. Uncontrolled greenbug infestations kill sorghum leaves and reduce grain yields (Teetes and Johnson, 1973). Damaging greenbug infestations may develop anytime from the seedling stage to early grain development, but are dependant on weather conditions and the presence of natural enemies. Sorghum producers limit their use of granular insecticides due to the uncertainty of greenbug infestations developing, the added expense of

applying insecticides, and the need for special application equipment. In addition, the application of insecticides at-planting may not provide sufficient residual control of mid- and late-season greenbug infestations in some areas (e.g. Nebraska) (Wright *et al.*, 1990). Foliar insecticides applied as-needed are often more cost effective, but their use requires knowledge of economic thresholds and a commitment of labor for field scouting. Economic thresholds based upon greenbug density, crop injury, and crop growth stage have been developed to assess the need for foliar treatments (Wright *et al.*, 1990; Anonymous, 1990; Fuchs *et al.* 1988; Teetes *et al.*, 1974).

Corn leaf aphid rarely causes economic damage to grain sorghum; however, large numbers may kill seedling plants. Yield losses may occur when infestations persist during or after heading, particularly when coupled with severe drought stress (Anonymous, 1990; Wright *et al.*, 1990; Almand *et al.*, 1969).

Chinch bug seriously reduces sorghum stands and grain yield (Pfadt, 1978). Chinch bug feeds at the base of the plant and large numbers can quickly kill seedling sorghum (Wilde and Morgan, 1978). Chinch bug populations are highest during hot and dry weather, which exacerbates crop injury. Parker *et al.* (1989) reported a net return of $35.04 per acre when chinch bug was controlled with terbufos compared to the untreated check.

Banks grass mite is a pest of sorghum in the southwestern United States during hot, dry weather. Application of insecticides significantly increases yields when Banks grass mite densities are high (Ward *et al.*, 1972).

The southern corn rootworm in an important pest in the upper Gulf Coast region of Texas, Alabama and Florida. Southern corn rootworm larvae tunnel into germinating seeds, roots and crowns of seedlings, resulting in reduced stands, delayed crop maturity, lodging, and lower yields.

The red imported fire ant (*Solenopsis invicta* Buren) is an occasional pest in Texas. The red imported fire ant feeds on sorghum seeds and seedlings, and reduces stands. At-planting granular insecticides and seed treatments provide effective control (Drees, 1988).

Wireworms, white grubs, lesser cornstalk borer (*Elasmopalpus lignosellus* [Zeller]), and nematodes are other soil dwelling pests which feed on roots and seedling plants.

Pest Management

Current Chemical Usage

The results of the National Agricultural Pesticide Impact Assessment Program (NAPIAP) survey indicate that granular insecticides are applied to 11.0 million acres of sorghum in 11 U.S states (Table 16). During the period 1985-89, an average of 21% (2.3 million acres) of the total United States acreage planted to sorghum was treated with granular insecticides.

Phorate and terbufos were applied to 11% and 25% of treated acreage, respectively (Table 16). Phorate is used in all the major sorghum producing states. The major usage of terbufos is in Texas, Kansas, Nebraska and Oklahoma. The relatively high usage of phorate in Texas is attributed to its efficacy, long residual action, and control of a broad spectrum of pests (greenbug, southern corn rootworm, chinch bug, yellow sugarcane aphid, and imported fire ant).

[illegible] applications [illegible] infestations [illegible] [illegible] sorghum infestations [illegible] applied as needed are often [illegible] [illegible] density, crop injury, [illegible] and for [illegible] treatments (Wright et al., [illegible]).

[illegible] economic status [illegible] plants. Yield losses may occur [illegible] [illegible] when [illegible] et al., 1969).

[illegible] of the [illegible] 1978). Chinch bug [illegible] crop injury. [illegible]

[illegible] is a pest of sorghum [illegible] [illegible] (Ward et al., [illegible]).

[illegible] corn rootworm [illegible] Southern corn [illegible] reduce stands, [illegible]

[illegible] feed on sorghum seeds [illegible] provide effective control.

[illegible] soil dwelling [illegible] which [illegible]

Pest Management

[illegible] the National Agricultural Pesticide Impact Assessment Program [illegible] treatments [illegible] 11.0 million [illegible] an average of 21% [illegible] sorghum was treated with granular insecticides.

[illegible] and 15% of treated sorghum [illegible] sorghum producing states. [illegible] and Oklahoma. The relatively high [illegible] [illegible] chinch bug [illegible]

Table 16. Phorate, terbufos, and alternative chemical usage in United States sorghum production, 1985-89[a]

State and chemical	Area planted	Area treated	Total[b] usage	% of usage
	(thousand acres)	(%)	(lb ai)	
Alabama	75	2	1,500	100
carbofuran		1	750	50
chlorpyrifos		1	750	50
California	29	8	2,320	100
phorate		8	2,320	100
Colorado	271	4	10,840	100
phorate		1	2,710	25
terbufos		1	2,710	25
aldicarb		1	2,710	25
carbofuran		1	2,710	25
Delaware	5	10	500	100
carbofuran		10	500	100
Florida	40	40	16,000	100
terbufos		7	2,800	18
carbofuran		8	3,200	10
chlorpyrifos		25	10,000	62
Louisiana	100	43	43,000	100
terbufos		3	3,000	7
carbofuran		40	40,000	93
Kansas	4,100	23	947,000	100
phorate		3	123,000	13
terbufos		3	123,000	13
aldicarb		1	41,000	4
carbofuran		15	618,000	65
disulfoton		1	41,000	4
Missouri	968	22	218,000	100
phorate		2	19,360	9
carbofuran		15	145,200	68
chlorpyrifos		5	48,400	23
disulfoton		0.5	4,840	2
Nebraska	1,500	8	120,000	100
terbufos		3	45,000	38
phorate		5	75,000	62
Oklahoma	478	4	19,120	100
terbufos		3	14,340	75
carbofuran		1	4,780	25
Texas	3,390	28	969,540	100
phorate		1	33,900	3
carbofuran		7	237,300	25
aldicarb		0.05	16,950	2
fonophos		1	33,900	3
chlorpyrifos		7	237,300	24
terbufos		12	406,800	42
disulfoton		0.1	3,390	0.3
U.S. Total[c]	12,290			

[a]Source: NAPIAP Phorate and Terbufos Surveys, 1990.
[b]Application rate is 1 lb ai/A.
[c]Source: USDA, 1988 and 1990.

It is estimated that sorghum yields would be reduced from 0% to 5% should phorate or terbufos usage be canceled (Table 17). Cancellation of phorate would increase the use of terbufos and carbofuran, cancellation of terbufos would increase the use of carbofuran, chlorpyrifos and phorate. Carbofuran and chlorpyrifos usage would increase proportionately should both terbufos and phorate be canceled. Because several chemical alternatives to phorate and terbufos are available, it is estimated that there would be a 0% to 10% yield reduction in sorghum yields should both chemicals be canceled (Table 17). Yield losses would be greater (1-13%) should all granular formulations be canceled, and would further increase, up to 16% if all at-planting insecticides were canceled.

Table 17. Estimated sorghum yield reduction if the registrations of phorate, terbufos, and alternative insecticides are canceled[a]

	Estimated yield reduction (%) if:				
State	Phorate unavailable	Terbufos unavailable	Both unavailable	All[b] granulars unavailable	All soil insecticides unavailable
Alabama	0	0	0	2	5
California	--	--	--	--	--
Colorado	0	0	0	0	0
Delaware	0	0	0	5	5
Florida	0	0	0	--	--
Louisiana	0	0	0	5	15
Kansas	1	1	2	10	11
Missouri	0	0.5	0.5	5	7
Nebraska	5	5	10	13	13
Oklahoma	0	0	0	1	1
Texas	0	1	1	5	16

[a]Source: NAPIAP Phorate and Terbufos Surveys, 1990.
[b]Liquid formulations of carbofuran and disulfoton are labeled for at-planting application to sorghum.

Chemical Alternatives for Pest Management

Foliar insecticides provide an alternative to at-planting granular insecticides for control of chinch bug. Economic thresholds based on chinch bug density and crop growth stage make it possible to apply foliar insecticides on an as-needed basis (Fuchs *et al.*, 1988). However, because injury can occur before rescue sprays can be applied, systemic insecticides applied at-planting are recommended where chinch bugs are historically a problem (Anonymous, 1990). A two day delay in rescue treatment to control chinch bug infesting seedling (3-inch) sorghum resulted in an 80-90% stand reduction in Kansas (Anonymous, 1990). Because chinch bug may continue to migrate from alternate hosts (e.g. wheat) (Pfadt, 1978), it is generally necessary to apply foliar insecticides several times to obtain adequate control. Dimethoate, disulfoton, propargite and methidathion are registered for spider mite control on sorghum. Foliar applications of insecticides are not effective for rescue treatments to control southern corn rootworm (Fuchs, 1988).

Carbofuran is labeled for control of southern corn rootworm, wireworm, white grubs, and nematodes and is an alternative to terbufos for control of these minor pests of sorghum. Planter box treatment with lindane may suppress low infestations of wireworms.

Non-Chemical Management Alternatives

Crop rotation is not effective for controlling greenbug, corn leaf aphid, or southern corn rootworm since they are mobile and are able to infest sorghum once it is established. Chinch bug infestations can be reduced by not planting sorghum adjacent to wheat, which serves as overwintering hosts (Anonymous, 1990). Nearby wheat fields can be scouted to estimate the potential for chinch bug problems and the need for the application of systemic insecticides at-planting (Anonymous, 1990). Trap crops and barrier strips may reduce the migration of chinch bugs into sorghum fields (Anonymous, 1990).

The use of sorghum varieties with resistance to greenbug is an important management practice for greenbug control on sorghum. Because resistance is expressed primarily as tolerance, foliar insecticides must be applied when infestations reach economic levels (Fuchs *et al.*, 1988; Dixon *et al.*, 1990). Significant levels of resistance to chinch bug and soil dwelling pests are not available in commercial sorghum hybrids. Some kafir sorghums may have some tolerance to mid-summer infestations of chinch bug (Anonymous, 1990; Meehan and Wilde, 1989).

Integrated Pest Management

Systemic insecticides such as phorate and terbufos applied to sorghum at planting provide control of greenbug, yellow sugarcane aphid, and corn leaf aphid during the critical period of germination and seedling establishment. Terbufos also controls southern corn rootworms and chinch bugs, which are difficult or impossible to control with rescue treatments. Terbufos is widely used in the Gulf Coast states to control this pest complex because it is efficacious and it provides a broad spectrum of pest control.

If systemic insecticides are not applied at planting, foliar insecticides can be applied when greenbug or other aphid infestations reach the economic threshold. However, optimum treatment timing may be prevented by adverse weather conditions and failure to monitor fields frequently. Sorghum resistance to greenbug is an important component of an IPM approach.

Potential for Pest Resistance

The use of at-planting insecticides like phorate and terbufos may increase selection pressure for resistance due to their longer residual activity relative to foliar applications. The potential for the development of resistance is relatively small because only a small percentage of sorghum acreage is treated. However, removal of phorate and terbufos would limit the number of chemicals available for use on sorghum, and would thereby increase the potential for the development of resistance. The potential for the development of pest resistance is reduced when classes of insecticides are alternated, and the cancellation of phorate and terbufos (organophosphates) would leave only carbofuran and aldicarb (carbamates) as control alternatives.

Comparative Performance Evaluation

One of the most important uses of terbufos on sorghum is to control chinch bug. Terbufos provides superior control relative to carbofuran in Texas and Louisiana (Parker *et al.*, 1989; Negron and Riley, 1988). Carbofuran, chlorpyrifos and aldicarb are registered alternatives to phorate and terbufos for chinch bug control. Aldicarb is not commonly used due to its high cost and its greater potential for leaching into ground water. Chlorpyrifos has not provided

consistent control in some areas (e.g. Nebraska), while in other areas (e.g. Texas and Louisiana) it has out performed carbofuran for chinch bug control (Parker *et al.*, 1989; Negron and Riley, 1988). However, chlorpyrifos does not have the systemic activity that is necessary to control greenbug. For this reason, carbofuran is the best alternative to phorate and terbufos for control of chinch bug.

Carbofuran, aldicarb and disulfoton are registered alternatives to phorate and terbufos that can be applied at-planting, providing systemic control of greenbug and corn leaf aphid. These three insecticides are as efficacious as phorate and terbufos for greenbug control, except in areas where greenbug resistance to disulfoton has developed (Teetes *et al.*, 1975; Anonymous, 1990). Carbofuran is commonly used for greenbug control because, unlike phorate, terbufos and disulfoton, it is not phytotoxic to sorghum seed and can be placed in the seed furrow. The ability to place this chemical in the seed furrow makes application easier and is an advantage during dry periods when there is insufficient moisture on the soil surface to activate insecticide granules. Aldicarb can also be placed in the seed furrow, but it is more expensive than the alternatives and it does not provide adequate control of southern corn rootworm. In Kansas, phorate has not provided consistent control of greenbug (Anonymous, 1990).

Outlook for New Chemical and Non-Chemical Controls

Very few new registrations of at-planting systemic insecticides for sorghum are expected. Tefluthrin was recently registered on corn and is reported to have activity against chinch bugs. However, it does not have the systemic activity necessary for control of greenbug.

Summary

In the 1990 NAPIAP Phorate Survey, the 11 major grain sorghum producing states reported that 21% of United States sorghum acreage is treated with a granular insecticide each year. Terbufos and phorate are used on approximately 598,000 and 255,000 acres per year, respectively. Terbufos usage is primarily in Texas, Kansas and Nebraska. Texas alone accounts for 71% of the sorghum acreage treated with terbufos. Terbufos is the granular insecticide of choice in Texas because of its efficacy against a broad spectrum of soil dwelling and seedling insect pests of sorghum. Phorate is used in most sorghum producing states and is one of the least expensive granular insecticides. Terbufos and phorate are used to control soil active pests and foliage feeding aphids.

Carbofuran would be the primary alternative insecticide used by sorghum producers should the registrations of terbufos and phorate be canceled. However, the cancellation of carbofuran in addition to phorate and terbufos would significantly impact sorghum production since the alternative insecticides (chlorpyrifos, disulfoton and aldicarb) do not provide an equal spectrum of pest control. The estimated yield loss should the registrations of both terbufos and phorate be canceled is small (0-5%) but assumes alternative granular and emulsifiable concentrate formulations remain available. The estimated yield reduction should all granular formulations be canceled ranges from 1% to 10%.

Granular insecticides incorporated into the soil are more effective for the control of soil active insect pests (southern corn rootworm, wireworm, chinch bug) than liquid formulations applied postemergence. Liquid formulations of several insecticides applied postemergence control foliage feeding aphids.

[illegible] 5%) it was outperformed [illegible] 1993). However, chlorpyrifos does not [illegible] control of chinch bug.

[illegible] are [illegible] dry periods [illegible] It does not [illegible] not granted our state [illegible]

[illegible] does not [illegible]

[illegible] limits are used [illegible] increases usage [illegible] of the sorghum crop [illegible] insect pests of soybeans [illegible] and foliage feeding [illegible]

[illegible] The estimated yield losses [illegible] from 5% to 10%.

[illegible] applications.

Phorate Use on Soybean

Darrell D. Hensley

Soybean (*Glycine max* [L.] Merrill) production in the United States averaged 1.9 billion bushels on an average of 60.8 million acres from 1985-88. More than half (62%) of United States soybean acreage is located in 9 midwestern states (USDA 1989, 1990). The remaining soybean acreage is located in the southern and southeastern states.

Registration Summary

Phorate is labelled for application to soybean as an at-planting band treatment to control Mexican bean beetle (*Epilachna varivestis* Mulsant), leafhoppers (Cicidillidae), aphids (Aphididae), lygus bugs (*Lygus* spp.), thrips (*Frankliniela* spp.), spider mites (*Eriophytes* spp.), and seedcorn maggot (*Delia platura* [Meigen]). Application rates range from 0.9 to 1.9 oz ai per 1,000 ft of row (minimum spacing 30 in) for Mexican bean beetle and 0.9 to 1.4 oz ai per 1,000 ft of row for other insects.

Pest Infestation and Damage

Several insect pests of soybean can have an economic impact on the crop. However, the only insect pests that granular insecticides are used to control are the seedcorn maggot and thrips. Yield losses and economic injury levels caused by thrips infestations have not been established in Illinois (Irwin and Yeargan, 1980). Heavy infestations of thrips did not cause yield loss in Arkansas (Mueller and Lutrell, 1977). However, thrips may be the primary vector of tobacco ringspot virus, which causes significant yield reductions in soybean (Crittenden *et al.*, 1966).

Pest Management

Current Chemical Usage

The results of the National Agricultural Pesticide Impact Assessment Program (NAPIAP) pesticide use assessment survey indicate that phorate use on soybean is minimal (Table 18). Only six states reported phorate usage on soybean, accounting for less than 0.1% of United States soybean acreage. Soybean producers rarely apply phorate or other alternative granular insecticides as an at-planting treatment for control of seedcorn maggot and thrips. In the few cases where a granular insecticide is applied, aldicarb and carbofuran are the insecticides most often selected since they also have nematicidal properties. Seed treatment is a relatively inexpensive alternative treatment that is used in Minnesota for effective control of seedcorn maggot.

Non-Chemical Management Alternatives

Soybean producers traditionally utilize crop rotation to control early season insect pests (Greene *et al.*, 1985). Soybean is often rotated with corn, sorghum, or cotton to reduce insect populations. Insect pest populations may also be reduced by incorporating a fallow period into the crop rotation.

Potential for Pest Resistance

The potential for pest resistance to phorate is low due to the small amounts that are applied to soybean. Selection pressure for pest resistance is negligible when usage is minimal (Metcalf and Luckman, 1982).

Table 18. Usage of phorate in United States soybean production, 1985-89[a]

State	Area planted	Area treated	Area treated
	(thousand acres)	(%)	(acres)
Pennsylvania	225	1	2,250
Nebraska	2,500	1	25,000
North Carolina	1,500	1	15,000
Florida	169	1	1,690
Delaware	240	5	12,000
Minnesota	5,050	1	1,000
U.S. Total	60,800	0.1	56,940

[a]Source: NAPIAP Phorate Survey, 1990.

Summary

Granular insecticides such as phorate are applied to soybean as an at-planting prophylactic treatment to provide early-season control of seedcorn maggot and thrips. In the few cases where a granular insecticide is applied to soybean, aldicarb and carbofuran are preferred since they also have nematicidal properties. Because phorate usage on soybean is minimal, the cancellation of this insecticide would not have an economic impact on the soybean industry.

Phorate and Terbufos Use on Sugarbeet

Hugh W. Homan and Susan P. Whitney

In the United States, sugarbeet (*Beta vulgaris* L.) is primarily processed into beet sugar and molasses. A processing byproduct, beet pulp, is used as a high protein livestock feed. Sugarbeet is grown in 13 states, which average 1.2 million acres and 25.4 million tons of sugarbeet with an average yield of 20.6 tons per acre (USDA, 1990). At the current market price of $38.79 per ton, the value of sugarbeet to producers exceeds $986 million. In addition, there is a significant benefit to local economies from sugarbeet processing. In Wyoming, sugarbeet processing provided 1,154 factory jobs with a payroll of $10.3 million in 1986, accounting for 6% of the non-farm jobs in three counties (USDA, 1989). Sugarbeet industries are considered to be essential to the economies of the communities in which they are located.

Registration Summary

Phorate is labeled for use on sugarbeet to control sugarbeet root maggot (*Tetanops myopaeformis* [Roder]), aphids (Aphididae), leaf miners (Anthomyiidae), spider mites (*Tetranychus* spp.), and leafhoppers (Cicadellidae). Phorate can be injected with ground equipment at a rate of 4.5 oz of 20% granular per 1,000 ft of row or the granules can be placed in a band over the row. It can also be applied to the foliage when the plants are dry at a rate of 4.9 to 7.5 lb of 20% granules per acre.

Terbufos is labeled for use on sugarbeet to control sugarbeet root maggot, wireworms (Elateridae), white grubs (Scarabaeidae), beet leafhopper (*Circulifer tenellus* [Baker]) and cutworms (Noctuidae), and to suppress cutworms and sugarbeet cyst nematode (*Heterodera schachtii* Schmidt). Terbufos can be applied at-planting modified in-furrow or banded at a rate of 4 to 8 oz of 15% granules per 1,000 ft of row for control of sugarbeet root maggot, wireworms, cutworms, or white grubs. Post-emergence applications can be banded at a rate of 8 oz per 1,000 ft of row. For the control of beet leafhoppers and for the suppression of sugarbeet cyst nematode terbufos can be knifed-in at a rate of 18 oz per 1,000 ft of row.

Pest Infestation and Damage

The sugarbeet root maggot causes injury and death to developing beets, deformity of mature beets, and yield loss. Infestation by sugarbeet root maggot is a problem throughout the upper-midwest and the Rocky Mountain region of the United States. Damage by sugarbeet root maggot is commonly at economically damaging levels in these production regions. In North Dakota, sugarbeet root maggot infestation reduces sugarbeet yield 50% when chemical controls are not used (A. Anderson, North Dakota State University, personal communication).

Several species of wireworms destroy sugarbeet seed before it germinates or damage the roots of developing sugarbeet. The beet leafhopper is the only known vector of the virus that causes curly top disease. Curly top disease causes stunting and death of sugarbeet.

White grubs are pests of sugarbeet grown in sandy soils previously used for production of a grass crop. Damage to sugarbeet is caused by the larval stage, which damage the below-ground portions of the plant. Damage from white grub is more severe during a drought period,

but yield is reduced even when adequate moisture is present. Damage to the root system also increases damage by secondary pathogens, which gain entry through damaged tissue.

Cutworms damage sugarbeet early in the season. Treatment with terbufos is effective if it coincides with the occurrence of cutworms. Cutworms, when plentiful, cut off the small sugarbeet plant at ground level, thus killing the plant. Clean cultivation when the adult moths are ovipositing will prevent egg laying.

Sugarbeet cyst nematode infestation causes the production of numerous rootlets from the sugarbeet, resulting in significant reductions in yield and sugar content. Heavy infestations can result in total loss of the crop.

Leaf miners burrow inside sugarbeet leaves and feed on leaf tissue. Chemical control of this insect is not normally necessary.

Infestation by aphids injures sugarbeet in two ways: 1) direct feeding, which causes plants to wilt, and 2) transmission of virus diseases such as beet yellows, western beet yellows, lettuce infectious yellows, beet yellow net, cucumber mosaic, and beet mosaic. The green peach aphid (*Myzus persicae* [Sulzer]) is the principle vector (Dunning and Byford, 1982).

Pest Management

Current Chemical Usage

Far West Region: California

Sugarbeet production in California accounts for 17% of total United States production. The primary insect pests in this production region are the green peach aphid, bean aphid and leafhoppers. Granular insecticides are applied to approximately 20% of sugarbeet acreage in California. Phorate is used on 70% of the acreage that is treated. Terbufos is not used in California sugarbeet production. Foliar applications of insecticides during the growing season account for 80% of insecticide usage on California sugarbeet. If the registration of phorate was canceled, it would be replaced by foliar applications of chlorpyrifos, methomyl, parathion, endosulfon, oxydemeton-methyl, and diazinon.

North-Central Irrigated Region: Montana, Idaho, Colorado, Wyoming, and Nebraska

Sugarbeet production in this region is in a rotational sequence on irrigated lands. This region accounts for 49% of sugarbeet production in the United States. The primary pest is the sugarbeet root maggot. Insects that cause occasional losses are flea beetle, wireworms, sugarbeet webworm, and beet leafhoppers. Phorate usage in this region ranges from 5% of total sugarbeet acreage in Idaho to no usage in Montana. If the registration of phorate were canceled, the impact on the sugarbeet industry would be small since its usage is so low in this region. Terbufos has a larger share of the market in this region. Terbufos is applied to 40% and 35% of sugarbeet acreage in Montana and Idaho, respectively. Sugarbeet root maggot is the primary pest in both of these states. In Colorado and Wyoming, terbufos is used on approximately 5% of total sugarbeet acreage.

... secondary pathogens ...

... sugarbeet ... the ... The ...
... ground level, ... the plant ...

... nematode infestation ...
... negligible reduction ...
... of the crop.

... normally ...

... beet yellow net, cucumber ...

Pest Management

Usage

California

... in California acres ...
... pests in this production region ...
... Granular insect ...
... is used on 70% of the acres ...
... production. Foliar application is ...
... used in California ...
... replaced by foliar ...
... and diazinon

... Montana, Idaho, Colorado, Wyoming ...

... in this region is in ...
... for 43% of sugarbeet production in the United States ...
... maggot. Insects that cause ... are ...
... and beet leafhoppers. Phorate usage ...
... in Idaho to no usage in Montana ...
... would be small ...
... of the market in this region ...
... Montana and Idaho ...
... these states. In Colorado and Wyoming ...
... sugarbeet acreage.

North-Central Dryland Region: Minnesota, North Dakota, Michigan, and Ohio

Sugarbeet root maggot and wireworms are the principle insect pests of sugarbeet in Minnesota and North Dakota. Terbufos is the most important insecticide used on sugarbeet in these states since it effectively controls the two primary insect pests. Wireworm damage is usually spotty, but yield losses can exceed 50% in some cases. Chlorpyrifos and aldicarb are generally quite effective on sugarbeet root maggot, but they provide inadequate control of wireworms. In Ohio and Michigan the principle pests are blister beetles, flea beetle, aphids, and leaf miners. Since the principle insect pests in Ohio and Michigan are above ground pests, adequate control is obtained with topical foliar sprays. Granular insecticides are used rarely in Michigan (less than 1% of total acreage is treated) and not at all in Ohio. Terbufos is essential to sugarbeet producers in North Dakota and Minnesota. There are no effective alternative chemicals for wireworm control and wireworms are a widespread problem in both states. The cancellation of both terbufos and phorate would cause serious production problems in North Dakota and Minnesota. Of the alternative chemicals (fonofos, diazinon, and carbofuran) only fonofos could replace terbufos, but planting equipment would have to be modified to accommodate this product.

South-West Region: Texas, New Mexico, and Arizona

Texas was the only state in this region that reported usage of granular insecticides. The primary insect pest targeted with granular insecticides is sugarbeet leafhopper. Phorate is used on 30% of Texas sugarbeet acreage; terbufos is not used. If the registration of phorate were canceled, carbofuran would be used on 80% of the acreage presently treated with phorate.

Non-Chemical Management Alternatives

Crop Rotation and Cultural Management: The effectiveness of crop rotation is reduced because the adult sugarbeet root maggot can fly up to five miles to find a sugarbeet field. The effectiveness of crop rotation is also reduced because 1) most rotational crops are also hosts of wireworms, and 2) the 3 to 7 year life cycle of wireworms makes it possible to raise sugarbeet (and other root crops) only every 6 to 8 years. Crop rotation is fairly effective for control of white grubs, although this insect has a three year life cycle. Control of white grubs can also be improved if fields are plowed in the fall before the grubs migrate to the lower depths of the soil profile. Fall plowing exposes white grubs to many parasites and predators. Crop rotation does not work well for sugarbeet cyst nematode because lambsquarter, a common weed, is also a host of the nematode. Wireworm infestations can be reduced by plowing fields in July prior to planting sugarbeet and then deep clean-cultivating through September (USDA, 1954), but these procedures are not practical because they are labor and energy intensive and crops cannot be grown in the field for one season. Corn can be used as a trap crop for wireworms (USDA, 1954). Reinfestation of fields by sugarbeet cyst nematode is minimized by not returning the tare to the field. This practice is followed by all producers. Even when chemical controls are available, sugarbeet should not be planted on land that is heavily infested with wireworms because sugarbeet production is not economically feasible under these conditions.

Host Plant Resistance: There is no host plant resistance to the sugarbeet root maggot. There are sugarbeet varieties with resistance to the virus causing curly top disease (Douglas and Cook, 1954), but the low yield of these varieties has limited their use by producers. In addition, the resistance of these varieties does not hold during dry years. Beet leafhopper can be successfully controlled with resistant varieties. However, chemical treatment is required when beet leafhopper populations are high (Douglas and Cook, 1954).

Sugarbeet [illegible] of the [illegible] are [illegible] and North Dakota. Temik [illegible] effectively controls the [illegible] but yield [illegible] generally quite effective [illegible] nematodes. In Ohio and Michigan, [illegible] Based on [illegible] control of [illegible] (less than 4% of [illegible] in North Dakota and M[illegible] for [illegible] and [illegible] of [illegible] is an [illegible] and Minnesota. [illegible] could replace [illegible] but [illegible] this product.

[illegible] was the only [illegible] insect pest targeted with [illegible] of Texas sugarbeet acreage [illegible], carbofuran would be used on 8[illegible]

[illegible] Management Alternatives

[illegible] and Cultural Methods. [illegible] the adult sugarbeet root [illegible] of crop rotation [illegible], and 2) the 3 [illegible] and other root crops only every two 3 years. [illegible] rotation is [illegible], although the insect has a [illegible] if fields are [illegible] Fall plowing, exposes [illegible] as well for sugarbeet cyst nematode [illegible] nematode. Wherever [illegible] can be [illegible] and then [illegible] incubation through [illegible] are not practical because they [illegible] energy intensive [illegible] the field for one season. Corn can be used as [illegible] of yields by sugarbeet [illegible] field. This practice is followed by [illegible] Even [illegible] sugarbeet should not be planted in field [illegible] production is not economically [illegible]

[illegible] Plant Resistance. There is no host plant resistance [illegible] sugarbeet varieties with resistance to the [illegible] top [illegible] 1984), but the low yield of these varieties has limited [illegible] The [illegible] does not [illegible] during dry years. [illegible] with resistant varieties. However, [illegible] are high (Douglas and Cook, 1984).

Integrated Pest Management

Integrated pest management (IPM) is not widely used to manage sugarbeet root maggot populations on sugarbeet. When an IPM program is used, granular insecticides are not applied at planting. Adult fly populations are monitored with sticky stakes. When 35 to 45 flies per stake are found between May 1 and June 1, a granular insecticide (phorate, terbufos, aldicarb, carbofuran) is applied as a band treatment (Bechinski *et al.*, 1989; Bechinski *et al.*, 1990). Peak fly emergence can be predicted with a growing-degree day model. The biggest problem with an IPM approach to pest management is that weather conditions may not permit the producer to apply the band treatment of insecticides. Producers do not want to risk losing a $1200 per acre crop because they did not apply a preventative soil insecticide at planting (cost of insecticide approximately $20 per acre).

Potential for Pest Resistance

There is not a significant potential for the development of pest resistance, except with aphids in California.

Summary

The cancellation of phorate and terbufos will have little impact on sugarbeet production as long as aldicarb remains as an alternative insecticide. If the registration of terbufos is canceled, sugarbeet producers in Minnesota and North Dakota will have to apply an extra insecticide treatment with a chemical such as dyfonate for wireworm control. This added treatment will require an extra trip through the field with application equipment, thereby increasing energy costs, reducing soil moisture, and placing extra stress on the crop.

[illegible] Management [illegible]

[illegible] When [illegible] possible [illegible]

[illegible] populations are [illegible]

[illegible] between May 1 and [illegible]

[illegible] is applied [illegible]

[illegible] can be predicted, and [illegible]

[illegible] exposed to new management [illegible]

[illegible] the best treatment [illegible]

[illegible] because they did not [illegible]

[illegible] approximately 525 per acre

[illegible] for Pest Resistance

[illegible] is not a significant potential in the [illegible]

[illegible]

[illegible] of private [illegible]

[illegible] programs [illegible]

[illegible] producers in Maine [illegible]

[illegible] a chemical [illegible]

[illegible]

soil moisture, and [illegible]

Phorate Use on Sugarcane

Don W. Dickson

In the United States, sugarcane (*Saccharum officinarum* L.) is a perennial crop that is grown commercially in Florida, Louisiana, Hawaii, Texas and the Commonwealth of Puerto Rico. An average of 877,350 acres of sugarcane was grown in the United States and Puerto Rico during the past 4 years (1985-89) (USDA, 1990). Sugarcane production in Florida accounted for 48% (417,500 acres) of United States production during the past four years. Because sugarcane is a three year perennial crop in Florida, only 135,000 acres (32%) is planted each year. The average yield of the planted and ratoon sugarcane crops is 32 tons per acre.

Sugarcane is grown from one-year old sugarcane stalks (seed cane) that are planted during the fall and winter months of the year. The stalks are cut into seed pieces and placed manually in a 15 inch wide x 4-8 inch deep seed furrow. The seed pieces are then treated with a soil insecticide and covered with 3 to 6 inches of soil.

Registration Summary

Phorate is registered for use in controlling corn wireworm (*Melanotus communis* Gyllenhal) in sugarcane seed cane plant sites at the rate of 3.9 lb ai/acre. The 20 G formulation is used almost exclusively in the Glades region of Florida. Florida is the only state in which phorate is registered for use on sugarcane. The granules are applied immediately before covering in a 10- to 12-inch band directly on seed pieces and the soil in the furrow (ca. 15 inches wide x 4-8 inches deep).

Pest Infestation and Damage

Corn wireworm is the most widespread and damaging soilborne pest on sugarcane in the Glades region of Florida (R.H. Cherry, University of Florida, personal communication). Infestation by corn wireworm occurs in both muck and sand soils, making necessary the application of a soil insecticide to all soil types before planting of sugarcane. Corn wireworm damages the eyes, lateral shoots, and young shoots of plant cane, therefore protection from infestation is needed until the plant is established. The damage threshold for stand reduction is three corn wireworm/5 row ft during plant cane germination (Hall, 1985). Corn wireworm infestation reduces cane stands by approximately 6% during 3 months of growth for each wireworm per 5 row ft. Sugarcane yield is reduced by 3.8% for each wireworm per 5 row ft (Hall, 1989).

Pest Management

Current Chemical Usage

Soil insecticides are applied to sugarcane at planting, which occurs every three to five years. The results of the National Agricultural Pesticide Impact Assessment Program (NAPIAP) pesticide use assessment survey indicate that each year approximately 128,250 acres (95%) of seed cane is treated with soil insecticides in Florida (Table 19). Phorate is used on approximately 81,000 acres (60%) of seed cane each year in Florida, the only state where it is

registered for use on sugarcane. Usage of soil insecticides is centered in the Glades region of Florida, primarily south of Lake Okeechobee in the counties of Palm Beach, Hendry, Glades and Martin. The amount of phorate used on sugarcane appears to be a result of tradition and competitive pricing.

Sugarcane production in Florida is controlled by approximately 30 producers, some of whom farm large tracts of land. Thus, a shift by one or two of the large producers results in a radical change in the use pattern of soil insecticides. The *Florida Insect Control Guide* (Johnson *et al.*, 1990) lists carbofuran, diazinon, ethoprop, ethyl parathion, fonofos, and phorate for wireworm control on sugarcane. Comparative efficacy data are not available for these six chemicals. However, each of the chemical alternatives provides effective control of corn wireworm (R.H. Cherry and F.J. Coale, University of Florida, personal communications). Contact toxicity studies indicate that all the chemicals are toxic to corn wireworm, but ethyl parathion has significantly greater toxicity; diazinon was not tested (Hall and Cherry, 1985). Sugarcane is produced on muck soils that are high in organic matter. Soil insecticides are bound tightly to the organic matter in this soil, thereby reducing the potential for leaching and run-off.

Non-Chemical Management Alternatives

Periodic flooding-fallowing for a 30 day period is an effective management alternative (Walker, 1968; Genung, 1970). However, the growing demand for water in south Florida may limit the use of this practice by growers. Water use restrictions were enforced in the Glades region by the South Florida Water Management District in 1989.

Corn wireworm densities can be effectively reduced by rotating sugarcane with paddy rice (F.J. Coale, University of Florida, personal communication). The rice crop is planted after the last harvest of sugarcane (stubble cane) in January. Sugarcane can be planted the following October, as is customary, but soil insecticides do not have to be applied.

Potential for Pest Resistance

There is a potential for corn wireworm resistance to soil insecticides, but resistance has not developed during the nearly 30 years that phorate has been used in sugarcane production (Jansson *et al.*, 1988). Resistance to phorate may have been avoided because corn wireworm populations are only exposed to the chemical once during a three to five year period.

Economic Impacts

Corn wireworm is widespread in all the areas where sugarcane is grown in Florida. It is projected that when plant cane is not treated with soil insecticide there is a yield loss of approximately 10% in the first harvest (Coale and Sosa, 1990). The yield of the ratoon crop may also be reduced when soil insecticides are not applied at planting (F.J. Coale, University of Florida, personal communication). Sugarcane quality is not measurably affected by wireworms (Coale and Sosa, 1990). With a projected 135,000 acres of replant cane and an average yield per acre of 32 tons, a 10% reduction in yield would amount to a loss of 432,000 tons of sugarcane. At the current price of $22/ton, the loss of all soil insecticides would cost the sugarcane industry approximately $9.5 million per year.

The cancellation of phorate would have a small impact on sugarcane producers since there are six soil insecticides registered for control of corn wireworm. Because the alternative

chemicals provide good control at a competitive price, producers can easily shift to one of the alternatives. The price of ethyl parathion is much lower than the price of phorate, yet it is only used on 5% of plant cane acreage (Table 20). However, two of the alternative chemicals (carbofuran and ethyl parathion) are under Special Review. Should several of the chemicals currently registered for control of corn wireworm be canceled, there would be a serious impact on sugarcane production in the United States.

Summary

Phorate is applied at planting to 60% of sugarcane acreage in Florida. On a national basis, approximately 30% of United States sugarcane is treated with phorate at planting. Phorate provides effective control of the corn wireworm, which is a serious insect pest of sugarcane. Phorate has an established use pattern on plant cane and is reasonable in cost. Approximately 316,000 lb ai of phorate are applied to sugarcane each year in Florida. There are five alternative chemicals registered for use on sugarcane, and research data indicate that they provide similar control to that provided by phorate. However, two of the alternatives, ethyl parathion and carbofuran, are currently under Special Review. Two of the remaining chemicals, diazinon and fonofos, are not currently used by sugarcane producers, but usage of these alternatives would probably increase should the other alternatives be canceled.

There are non-chemical management alternatives available to sugarcane producers. Flooding provides good control of corn wireworm, but recent water management regulations in southern Florida may restrict the use of this practice by sugarcane producers. Rotation of sugarcane with paddy rice also provides good control of corn wireworm, however this practice is only feasible if the rice crop can be produced profitably.

Table 19 Phorate and alternative chemical usage in Florida sugarcane production, 1986-89[a]

Chemical	Area[b] planted	Area treated	No.[c] treatments per year	Treatment rate	Total chemical used	% of usage
	(acres)	(%)		(lbs ai/A)	(lbs ai/yr)	
phorate		60	1	3.9	315,900	63
ethoprop		25	1	4.8	162,000	26
carbofuran		5	1	4.3	29,025	5
ethyl parathion		5	1	2.0	5,400	5
All chemicals	135,000	95	---	---	512,325	100

[a]Source: NAPIAP Phorate Survey, 1990.
[b]Acreage replanted with seed cane. Sugarcane is replanted every three years in Florida.
[c]Soil insecticides are only applied to seed cane, which is planted every three years, so the number of treatments per year can be considered as one-third.

Table 20. Comparative economic impact of phorate and alternative chemical usage in Florida sugarcane production, 1986-89[a]

Chemical	Area[b] treated	Chemical[c] price	Total[d] treatment cost	Yield with treatment	Yield loss w/o treatment	Average crop market price	Net[e] benefit	Total[f] net benefit
	(acres)	($/lb ai)	($/A/yr)	(lb/A)	(%)	($/lb)	($/lb/yr)	($/state)
phorate	81,000	6.15	23.99	6,400	10	22	14,056	1,138,536
ethoprop	33,750	6.25	30.00	6,400	10	22	14,050	474,188
carbofuran	6,750	8.67	37.28	6,400	10	22	14,043	94,788
ethyl parathion	6,750	2.34	4.68	6,400	10	22	14,075	95,008
All chemicals	128,250	24.41	95.95	6,400	10	22	56,224	1,792,520

[a]Source: NAPIAP Phorate Survey, 1990.
[b]Area planted x (% area treated/100).
[c]Source: B.Y. Mason, 5401 Westside Drive, El Paso, TX. (December 1989).
[d](Cost of chemical x total chemical used) + cost of application. Cost of applications is negligible because insecticide is applied during planting.
[e][avg yield/treatment x (% avg yield loss/100) x avg price] - total treatment cost.
[f]Net benefit x area treated.

Phorate Use on Wheat

Gary L. Jensen

Small grains are grown in virtually every state in the United States, but production statistics are available only for wheat, the most important of the small grains (USDA, 1989). Not included in the national statistics are the six New England states, Alaska, and Hawaii. The top five wheat producing states (in decreasing order) are Kansas, North Dakota, Montana, Oklahoma and Texas. The average United States wheat production from 1986-87 was two billion bushels per year. Statistics for barley production are available for 28 states, with United States production concentrated in the North-Central and Northwest (USDA, 1989). The principle barley producing states (in decreasing order) are North Dakota, Montana, Idaho, Minnesota, Washington and South Dakota. The average United States barley production from 1986-87 was six million bushels per year. Average oat production is similar to barley; however, the primarily producers (in descending order) are South Dakota, Montana, Wisconsin, Iowa and North Dakota (USDA, 1989).

Registration Summary

Phorate is labeled for use on wheat to control aphids, grasshoppers, and Hessian fly (*Mayetiola destructor* [Say]). Phorate can be applied in the seed furrow at planting at a rate of 0.24 oz ai (1.6 oz 15% or 1.2 oz 20%) per 1,000 ft of row with any row spacing (minimum 8-inch spacing). Phorate can be broadcast evenly over the field at a rate of 0.98 lb ai (4.9 lb 20%) per acre with air or ground equipment to control aphids. Only one broadcast application can be made per season.

Pest Infestation and Damage

In the west and midwest, where the heaviest concentration of small grains are produced, grasshoppers and aphids are the primary target insects for treatment with phorate. Damage from aphids results primarily from the Russian wheat aphid (*Diuraphis noxia* [Mordvilko]) and greenbug (*Schizaphis graminum* [Rondani]). The Russian wheat aphid, which is now found in 15 states, can reduce yields by up to 70% (Pfadt, 1985).

Greenbugs are very destructive insect pests of small grains in the Great Plains region (Pfadt, 1985). Large populations of greenbugs can cause total loss of both winter and spring wheat (Pfadt, 1985). Grasshoppers do not cause significant damage to small grains most years, but they occasionally damage entire fields. Grasshopper populations of 25 to 75 per yd^2 may completely destroy all vegetation (Pfadt, 1985).

In Florida and Alabama, the Hessian fly is the primary target pest for applications of phorate. Wheat infested by Hessian fly larvae may not survive the winter, or yields may be reduced by 25% to 30% (Pfadt, 1985). Phorate is used to control Hessian flies and grasshoppers in Missouri.

Pest Management

Current Chemical Usage

The results of the National Agricultural Pesticide Impact Assessment Program (NAPIAP) Phorate Survey indicate that phorate is not used in the large small grain producing states and many other key small grain producing states (Nebraska, California, Idaho, Oregon). With exception of Florida, no state reported phorate usage on more than 6% of small grain acreage (Table 21). The cancellation of the registration of phorate would not have a significant effect on small grain production in most states, but the impact would be greater in states that use this insecticide for broad spectrum insect control (Idaho, Oregon and Washington). In South Dakota and Montana, phorate is important for control of grasshoppers during years with severe infestations (G. Johnson, Montana State University and H. Homan University of Idaho, personal communications). The alternative insecticides that would replace phorate are disulfoton and carbofuran. Carbofuran and disulfoton are equally efficacious, but are more expensive than phorate. However, these alternatives are slightly more hazardous to applicators and the environment.

Table 21. Phorate usage for United States wheat production[a]

State	Area harvested	Area treated
	(acres)	(%)
Alabama	252,000	5
California	634,000	3
Colorado	2,977,500	<1
Florida	108,000	20
Idaho	1,395,000	4
Missouri	1,570,000	5
Montana	5,075,000	6
Oregon	1,000,833	4
Wyoming	300,000	<1
U.S. Total[b]	71,123,000	

[a]Source: NAPIAP Phorate Survey, 1990.
[b]Source: USDA, 1988 and 1990.

Non-Chemical Management Alternatives

Resistant varieties and mechanical controls (e.g. elimination of alternate hosts) can be used with limited success as an alternative control of grasshoppers and Russian wheat aphid. Planting times can be altered to avoid peak infestations of insects such as the Russian wheat aphid, which can be a serious pest of early planted winter wheat. Grasshopper infestations can be reduced by planting spring wheat earlier, so that grasshoppers do not have time to reach the most damaging stage in their lifecycle (third instar stage) (G. Johnson, Montana State University, personal communication). Trap strips have been used effectively for grasshopper control in Montana (R. Ashley, Cooperative Extension Service, personal communication). Trap strips of barley are planted around wheat fields if early scouting indicates a large population of grasshoppers. The barley strips are treated with a systemic insecticide at planting so that grasshoppers that feed on the barley are killed. Migrations of grasshoppers are reduced for some time by these insecticide treated trap strips. Once the systemic pesticides are no longer

effective, foliar sprays can be used to control the grasshoppers that are still attracted to the strips.

Resistant wheat varieties are used to a limited extent in the southern and southeastern states to reduce damage by Hessian fly. Planting free dates cannot be used in southern Georgia or in Florida because the Hessian fly has multiple generations (W. Gardner, Georgia Agricultural Experiment Station, personal communication).

Integrated Pest Management

Integrated Pest Management (IPM) has been used in small grains production for ten years in Montana (G. Jensen, Montana State University, personal communication). Scouting is used as a means to educate producers about pest population impacts on small grains production and to minimize applications of insecticides for pest control (Cooperative Extension Service, 1985).

Potential for Pest Resistance

Total dependency on a limited number of insecticides to control insects always increases the potential for the development of pest resistance. Therefore the loss of phorate would increase the potential for pest resistance to develop, particularly among populations of aphids and Hessian fly.

Summary

The cancellation of the phorate registration would have little or no impact on small grains production in some states, but would have a major impact in others. Wheat production in the southeastern United States would be impacted most by the cancellation of phorate. Alternative insecticides provide adequate control in some cases, but their use in other situations would result in small yield reductions. The cancellation of phorate would hamper grasshopper control in some northwestern states (Washington, Oregon, Idaho, Montana) during years with severe infestations. The potential for the development of pest resistance is not a major concern should the registration of phorate be canceled.

Economic Impacts Associated with the Discontinued Use of Phorate and Terbufos

Craig D. Osteen and Joe F. Guenthner

Methodology

Estimates of phorate and terbufos usage and the economic impacts which would result should their registrations be canceled have been developed based upon the 1990 National Pesticide Impact Assessment Program (NAPIAP) Phorate and Terbufos Surveys. Economic impacts were calculated from estimates of: 1) current usage of the granular insecticides, 2) alternative usage of granular insecticides should the registrations of one or both phorate and terbufos be canceled, and 3) the per-acre cost change associated with the use of these alternative granular insecticides. Economic impacts include changes in crop prices, output and producer income; consumer impacts; and net economic impact. Net economic impact is the sum of consumer impacts and the change in net producer revenue computed at the farm level. Net economic impact is a measure of the efficiency impact caused by the cancellation of a pesticide registration. Consumer impact is an approximation of the change in consumer surplus, which accounts for the effects of changes in prices and quantities consumed. The approximation assumes a linear demand function. The estimates of economic impacts presented in this report are valid only in the short-run since they do not take into account acreage adjustments in response to price, yield and cost changes. The economic parameters that where used in this analysis were computed as follows:

- Change in farm-level commodity price: $N = Y(A_t/100)/E$

  where N = change in farm-level commodity price (%)
  Y = yield reduction per treated acre (%)
  A_t = acres treated with the assessed pesticide (%)
  E = price elasticity of demand (% Δ quantity/% Δ price)

- Total change in production cost: $C = D(A_t/100)(A_p)$

  where C = total change in production cost ($)
  D = change in production cost per treated acre ($/A)
  A_t = acres treated with the assessed pesticide (%)
  A_p = number of acres planted

- Consumer Impact: $CI = (P_a - P_b)(Q_a + Q_b)/2$

  where CI = consumer impact ($)
  P_b = average market price before assessed pesticide is canceled ($/unit)
  $P_a = P_b(1+N/100)$
  N = change in farm-level commodity price (%)
  Q_b = commodity production before assessed pesticide is canceled (lb/unit)
  $Q_a = Q_b[1-(Y/100)(A_t/100)]$
  = commodity production after assessed pesticide is canceled
  Y = yield reduction per treated acre (%)
  A_t = acres treated with the assessed pesticide (%)

• Change in Net Producer Revenue: $CR = (P_aQ_a)-(P_bQ_b)-C$

where CR = change in net producer revenue ($)
P_b = average market price before assessed pesticide is canceled ($/unit)
Q_b = commodity production before assessed pesticide is canceled ($/unit)
$P_a = P_b(1+N/100)$
N = change in farm-level commodity price (%)
$Q_a = Q_b[1-(Y/100)(A_t/100)]$
Y = yield reduction per treated acre (%)
A_t = acres treated with the assessed pesticide (%)
C = change in production cost ($)

The change in commodity program deficiency payments that occur as a result of price changes are approximated by $M(P_a-P_b)Q_b$, where M is the proportion of crop acreage in the commodity program. Commodity program deficiency payments computed with this formula are overestimates because they are based on estimates of farm program yields that are generally lower than actual yields. Because commodity program deficiency payments are transfers from taxpayers to commodity producers, a change in deficiency payments affects producer income but does not alter the net economic impact caused by the cancellation of the assessed pesticide.

Estimated Economic Impacts

Beans: Phorate is applied to approximately 2% of United States dry bean acreage, accounting for 23,000 lb ai of annual usage (Table 22). Bean yields would not be reduced since the alternative insecticides provide effective control of insect pests. However, treatment costs would increase about $10 per acre on the acreage currently treated with phorate (Table 24). Dry bean producers would lose $235,000 per year should phorate be canceled (Table 25). Phorate is applied to approximately 12% of United States snap bean acreage, accounting for 26,000 lb ai of annual usage (Table 22). Snap bean producers would use disulfoton or dimethoate should phorate be canceled. Snap bean yields would not be affected, but treatment costs would increase about $3 per acre on the acreage currently treated with phorate (Table 24). As a result, snap bean producers would lose about $90,000 per year (Table 25).

Corn: Phorate is applied to approximately 2.2 million acres (3%) of corn in the United States (Table 22). Corn yields would decline less than 1% and production costs would increase about $3 per acre on acreage currently treated with phorate (Table 24). Market price would not be significantly affected by the cancellation of phorate. The use of the chemical alternatives would increase treatment costs about $5 per treated acre, resulting in a loss to corn producers of approximately $10 million per year (Table 25).

Terbufos is applied to approximately 9.8 million acres (15%) of corn in the United States (Table 23). Corn yields would be reduced by about 5% and treatment costs would increase slightly should terbufos no longer be available for pest control (Table 26). It is estimated that corn prices would increase less than 2% (Table 27). The cancellation of terbufos would result in a $131 million increase in corn producer revenues, however an increase in the price of corn will reduce government deficiency payments by $206 million (assuming 1985-89 average production and prices, and program participation of 82.4%). As a result, corn producers would realize a loss of $75 million after the payment reduction is considered. The cost to corn consumers would be $249 million per year. The overall net economic impact (sum of consumer and producer impacts) caused by the cancellation of terbufos would be a loss of $118 million (Table 27). Since the

change in commodity program payments is a transfer between producers and taxpayers, it does not affect the net economic impact.

If both phorate and terbufos are canceled, corn yields will be reduced an average of 5% and production costs will increase about $0.15 per acre on the 12 millions acres (18%) of United States corn treated with these two insecticides (Table 28). The cancellation of phorate and terbufos would result in a $138 million increase in producer revenues, however an increase in the price of corn would reduce government deficiency payments by $236 million. As a result, corn producers would realize a loss of $98 million after the payment reduction is considered. The cost to corn consumers would be $284 million per year. The net economic impact (sum of producer and consumer impacts) caused by the cancellation of phorate and terbufos would be a loss of $146 million (Table 29).

The economic impact should the registrations of terbufos or both terbufos and phorate be canceled would be a loss of $12 per treated acre on acreage under the commodity program, a loss of $8 per treated acre on acreage not under the commodity program, and a gain of $4 per untreated acre on acreage not under the commodity program.

Cotton: Phorate is applied to approximately 410,000 acres (4%) of cotton in the United States (Table 22). On cotton acreage currently treated with phorate, yields would increase by 3% and production costs would increase $6 per treated acre should phorate be canceled (Table 24). The net economic impact caused by the cancellation of phorate would be a gain of $2.3 million dollars (Table 25).

Peanut: Phorate is applied to approximately 160,000 acres (10%) of peanut in the United States (Table 22). Peanut yields will increase slightly on acreage treated with alternative insecticides, but production costs will increase nearly $6 per acre (Table 24). The net economic impact caused by the cancellation of phorate would be a net loss of $660,000 (Table 25).

Potato: Phorate is applied to approximately 511,000 acres (40%) of potato in the United States (Table 22). Phorate usage has increased significantly since 1988, when it was applied to 16% of potato acreage. Phorate has replaced aldicarb on much of the potato acreage formally treated with aldicarb. Aldicarb was voluntarily withdrawn by the registrant in 1990. Yield losses may reach 10% in several states (Michigan, Ohio and Montana), but the average yield loss would be less than 1 percent on treated acreage (Table 24). The use of the chemical alternatives would increase treatment costs about $12 per treated acre. The net economic impact caused by the cancellation of phorate would be a net loss of $8.6 million (Table 25).

Sorghum: Phorate and terbufos are applied to approximately 295,000 (2%) and 651,000 (5%) acres, respectively, of sorghum in the United States (Tables 22 and 23). Sorghum yields would decline about 2% and production costs would increase about $3 per treated acre if phorate were canceled (Table 24). The economic impact caused by the cancellation of phorate would be a net loss of $1.5 million (Table 25). If the registration of terbufos were canceled, the yields of treated sorghum acreage would decline 1% and production costs would decline more than $1 per acre (Table 26). The economic impact caused by the cancellation of terbufos would be a net loss of $165,000 (Table 27).

If the registrations of both phorate and terbufos are canceled, sorghum yields on treated acreage would be reduced by 2% percent and production costs would increase less than $1 per treated acre (Table 28). The overall economic impact caused by the cancellation of both phorate and terbufos would be a net loss of $2.3 million (Table 29).

Soybean: Phorate is applied to approximately 59,000 acres (0.1%) of soybean in the United States (Table 22). The net economic impact caused by the cancellation of phorate would be negligible (Table 25).

Sugarbeet: Phorate and terbufos are applied to approximately 47,000 (4%) and terbufos is applied to 298,000 (24%) acres of sugarbeet in the United States (Tables 22 and 23). Sugarbeet yields on treated acreage would decline 1% and production costs would increase $23 per treated acre if phorate were canceled (Table 24). The economic impact caused by the cancellation of phorate would be a net loss of $1.4 million (Table 25). If the registration of terbufos were canceled, the yields of treated sugarbeet acreage would decline about 2% and production costs would increase $13 per treated acre (Table 26). It is estimated that sugarbeet prices would increase 2%, assuming that sugar import quotas do not change (Table 27). As a result, the cancellation of terbufos would cost consumers $20 million, but sugarbeet producers would gain $11.2 million per year (Table 27). The economic impact caused by the cancellation of terbufos would be a net loss of $8.8 million.

If the registrations of both phorate and terbufos are canceled, sugarbeet yields would be reduced more than 2% and production costs would increase more than $15 per acre on treated acreage (Table 28). It is estimated that sugarbeet prices would increase 3% percent, assuming that sugar import quotas do not change (Table 29). As a result, the cancellation of both phorate and terbufos would cost consumers $28 million, but sugarbeet producers would gain $16 million per year. The overall economic impact caused by the cancellations of phorate and terbufos would be a net loss of $12 million.

Sugarcane: Phorate is applied to approximately 81,000 acres (32%) of the sugarcane that is replanted in the United States each year (Table 22). Phorate accounts for 60% of soil insecticide usage on replanted sugarcane in Florida, the only state in which it is registered for use on sugarcane. Sugarcane yields would not be affected and production costs would decrease slightly should phorate be canceled (Table 24). The net economic impact caused by the cancellation of phorate would be a negligible gain of $12,000 (Table 25).

Wheat: Phorate is applied to approximately 284,000 acres (0.4%) of wheat in the United States (Table 22). Wheat yields on treated acreage would not be reduced should phorate not be available and it is estimated that production costs would increase less than $1 per acre (Table 24). The net economic impact caused by the cancellation of phorate would be a loss of $171,000 (Table 25).

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Summary

The estimated short-term economic effect (sum of consumer and producer effects) of the cancellation of phorate would be a loss of $21 million per year. The economic effect of cancellation would be greatest to corn and potato producers, who would lose $10.0 million and $8.6 million per year, respectively. The cancellation of phorate would have minimal effects on commodity prices and consumers.

The economic impact caused by the cancellation of terbufos would be a loss of approximately $127 million, including a loss of $118 million by corn producers and consumers. Should the registrations of both phorate and terbufos be canceled, the economic loss would be $168 million, including a loss of $146 million by corn producers and consumers. The cancellation of terbufos would cause a short-term increase in corn and sugarbeet prices of less than 5%. Consumers of corn and sugarbeet products would consume less and pay more as a result. Net market revenues of these two crops would increase. However, corn commodity program participants who are users of phorate or terbufos would suffer a net loss because commodity program payments would decrease more than their net market revenues would increase. The cancellation of the registrations of terbufos, or both phorate and terbufos, would have minimal economic impacts on the prices of other crops for which they are registered.

Table 22. Phorate usage in United States agriculture, 1985-89[a]

Crop	Area planted	Average production	Production unit	Average market price	Area treated	Treatment rate	Total chemical applied
	(thousand acres)	(thousands)		($)	(%)	(lbs ai/A)	(thousand lb ai)
beans							
dry	1,537	22,936	CWT	22.18	1.5	1.0	23
snap	220	687	tons	166.20	12.0	1.0	26
corn	65,307	7,329,397	bushels	2.09	3.4	1.0	2207
cotton	10,006	13,120	bales	273.60	4.1	0.7	290
peanut	1,561	3,915,312	pounds	0.27	9.8	0.9	142
potato	1,277	374,880	CWT	5.24	43.4	3.0	1651
sorghum	12,290	798,611	bushels	1.80	2.4	1.0	289
soybean	58,725	1,885,373	bushels	5.74	0.1	1.0	59
sugarbeet	1,230	25,222	tons	37.28	3.8	1.1	53
sugarcane	253[b]	29,532	tons	28.13	32.0[c]	3.9	304
wheat	71,123	2,139,212	bushels	3.12	0.4	1.0	284
Total							5329

[a]Sources: USDA, 1988 and 1990; NAPIAP Phorate and Terbufos Surveys, 1990.
[b]Acreage replanted with seed cane. Sugarcane is replanted every three to five years.
[c]Phorate is applied on sugarcane only in Florida, the only state where it is registered for use on sugarcane.

Table 23. Terbufos usage in United States agriculture, 1985-89[a]

Crop	Area planted	Average production	Production unit	Average market price	Area treated	Treatment rate	Total chemical applied
	(thousand acres)	(thousands)		($)	(%)	(lb ai/A)	(thousand lb ai)
corn	65,307	7,329,397	bushels	2.09	15.0	1.0	9,783
sorghum	12,290	798,611	bushels	1.80	5.3	1.0	651
sugarbeet	1,230	25,222	tons	37.28	24.2	1.2	348
Total							10,783

[a]Sources: USDA, 1988 and 1990; NAPIAP Phorate and Terbufos Surveys, 1990.

Table 24. Estimated change in crop production if phorate is replaced by alternative insecticides

Crop	Change in[a] yield	Change in production	Production unit	Change in production cost	Total change in production cost
	(%)	(thousands)		($/A)	($)
beans					
dry	0.0	0	tons	10.20	235
snap	0.0	0	tons	3.40	90
corn	-0.7	-1,684	bushels	3.05	6,733
cotton	3.2	17	bales	5.93	2,456
peanut	0.2	803	pounds	5.75	877
potato	-0.3	-423	CWT	11.50	6,373
sorghum	-2.1	-388	bushels	2.90	838
soybean	0.0	0	bushels	0.00	0
sugarbeet	-1.0	-9	tons	23.25	1,087
sugarcane	0.0	0	tons	-0.15	-12
wheat	0.0	0	pounds	0.60	171
Total					18,848

[a]Source: NAPIAP Phorate Survey, 1990.

Table 25. Economic impact on United States agriculture if phorate is replaced by alternative insecticides

Crop	Change[a] in price	Change[b] in net revenue	Consumer impact	Net economic impact
	(%)	(thousand $)	($)	(thousand $)
beans				
dry	0	-235	0	-235
snap	0	-90	0	-90
corn	0	-10,253	0	-10,253
cotton	0	2,299	0	2,299
peanut	0	-660	0	-660
potato	0	-8,590	0	-8,590
sorghum	0	-1,537	0	-1,537
soybean	0	0	0	0
sugarbeet	0	-1,430	0	-1,430
sugarcane	0	12	0	12
wheat	0	-171	0	-171
Total		-20,655	0	-20,655

[a]Change in farm-level commodity price (N).
[b]Change in net producer revenue (CR).

Table 26. Estimated change in crop production if terbufos is replaced by alternative insecticides

Crop	Change in[a] yield	Change in production	Production unit	Change in production cost	Total change in production cost
	(%)	(thousands)		($/A)	($)
corn	-5.4	-59,728	bushels	-0.80	-7,826
sorghum	-1.2	-508	bushels	-1.15	-749
sugarbeet	-2.1	-129	tons	13.23	3,939
Total					-4,636

[a]Source: NAPIAP Terbufos Survey, 1990.

Table 27. Economic impact on United States agriculture if terbufos is replaced by alternative insecticides

Crop	Change[a] in price	Change[b] in net revenue	Consumer impact	Net economic impact
	(%)	(thousand $)	($)	(thousand $)
corn	2	130624[c]	-248646	-118023
sorghum	0	-165	0	-165
sugarbeet	2	11234	-20048	-8815
Total		141692	-268695	-127003

[a]Change in farm-level commodity price (N).
[b]Change in net producer revenue (CR).
[c]Since corn price would increase, commodity program deficiency payments would decrease $206 million. When the change in payments is considered, corn producers would lose $75 million.

Table 28. Estimated change in crop production if phorate and terbufos are replaced by alternative insecticides

Crop	Change in yield	Change in[a] production	Production unit	Change in production cost	Total change in production cost
	(%)	(thousands)		($/A)	($)
beans					
dry	0.0	0	tons	10.20	235
snap	0.0	0	tons	3.40	90
corn	-5.1	-68,360	bushels	0.15	1,799
cotton	3.2	17	bales	5.93	2,456
peanut	0.2	803	pounds	5.75	877
potato	-0.3	-423	CWT	11.50	6,373
sorghum	-1.8	-1,100	bushels	0.30	282
soybean	0.0	0	bushels	0.00	0
sugarbeet	-2.5	-179	tons	15.35	5,288
sugarcane	0.0	0	tons	-0.15	-12
wheat	0.0	0	pounds	0.60	171
Total					17,559

[a]Source: NAPIAP Phorate and Terbufos Surveys, 1990.

Table 29. Economic impact on United States agriculture if phorate and terbufos are replaced by alternative insecticides

Crop	Change[a] in price	Change[b] in net revenue	Consumer impact	Net economic impact
	(%)	(thousand $)	($)	(thousand $)
beans				
dry	0	-235	0	-235
snap	0	-90	0	-90
corn	2	138,410[c]	-284,414	-146,004
cotton	0	2,299	0	2,299
peanut	0	-660	0	-660
potato	0	-8,590	0	-8,590
sorghum	0	-2,261	0	-2,261
soybean	0	0	0	0
sugarbeet	3	15,690	-27,764	-12,075
sugarcane	0	12	0	12
wheat	0	-171	0	-171
Total		144,403	-312,178	-167,775

[a]Change in farm-level commodity price (N).
[b]Change in net producer revenue (CR).
[c]Since corn prices would increase, commodity program deficiency payments would decrease $236 million. When the change in payments is considered, corn producers would lose $98 million.

Effects of Phorate and Terbufos on Wildlife

Scott E. Hygnstrom

Several factors contribute to the risks of a pesticide to non-target wildlife. The most important factors are 1) the behavioral traits of non-target wildlife and 2) the toxicity, environmental persistence, and bio-availability of the parent pesticide compounds and their residues. Direct effects of pesticide exposure to wildlife include mortality of adults, juveniles, and young. Sublethal exposure can also affect survival and reproduction. Exposure to organophosphate insecticides can be lethal or teratogenic to avian embryos (Hoffman and Albers, 1984) and can lead to anorexia and reduction of body weight in birds and mammals (Grue *et al.*, 1983). Loss of body weight may result in greater susceptibility to environmental stress (Grue *et al.*, 1986) and may affect reproduction by inhibiting egg production (Stromborg, 1981), reducing litter size (Spyker and Avery, 1977), or retarding growth of young (Grue and Shipley, 1984). Indirect effects of pesticides on food and cover used by wildlife is also a concern. Pesticide-induced reduction of invertebrate abundance has resulted in abandonment of nests, reduced survival of young, and emigration (Grue *et al.*, 1986).

The mechanisms of chemical exposure vary among wildlife species, largely because of differences in behavioral traits. Birds, especially waterfowl (Anseriformes spp.), appear to be the wildlife group most at risk because their food habits and flocking behavior tend to concentrate them in areas where agricultural chemicals are used. In terrestrial habitats, ingestion of pesticides directly or by way of contaminated food and water are believed to be the primary routes of wildlife exposure to pesticides (Grue *et al.*, 1983). In wetland habitats, ingestion and dermal absorption are primary routes of exposure, particularly for those species that spend a significant amount of time in the water (Grue *et al.*, 1986). In addition, there are several anatomical, physiological, and biochemical factors that make birds more susceptible to pesticides than mammals (Walker, 1983).

Phorate is extremely toxic to birds and mammals given either oral or dermal exposure (Smith, 1987). The acute oral toxicity (LD_{50}) and the purity (%) or grade are: rat (*Rattus rattus*) (0.6-3.7 mg/kg, 90%), northern bobwhite (*Colinus virginianus*) (7.0-21.0 mg/kg, technical and 15G), and mallard (*Anas platyrhynchos*) (0.6-2.6 mg/kg, 88% and 98.8%). Acute dermal toxicities (LD_{50}) are: rat (2.5-6.2 mg/kg, technical) and mallard (203.0 mg/kg, 88%). The parent compound of phorate and its oxidative products, phosphorodithiolate sulfoxide and sulfone, are both potent and irreversible cholinesterase inhibitors (Bowman and Casida, 1958; McCarty *et al.*, 1969; Hill and Fleming, 1982). The low predicted bioconcentration factor and moderate to high soil adsorption coefficient of phorate are indications that it is not highly persistent in the environment (Smith, 1987). The parent compound and oxidative products may persist beyond 16 weeks in silt loam soil (Getzin and Shanks, 1970). In water-saturated soils phorate is more persistent, leading to a reduction of oxidative products to the more toxic parent compound (Walter-Echols and Lichtenstein, 1978).

Terbufos is extremely toxic to mammals given either oral or dermal exposure (Smith, 1987). Although birds are typically more susceptible to pesticides than mammals, there currently are few data available for terbufos toxicity. Acute oral toxicities (LD_{50}) are: rat (4.5-9.0 mg/kg, technical), and northern bobwhite (15.0-26.0 mg/kg, technical and 15G). No acute dermal LD_{50} data are available. Both the parent compound and its oxidative product, phosphorodithiolate sulfoxide, are potent and irreversible cholinesterase inhibitors (Labisky, 1975; Laveglia and Dahm, 1975). Field and laboratory data indicate that the bioaccumulation and persistence of

terbufos in the environment is relatively low (Smith, 1987). Residues of terbufos in corn forage ranged from undetectable amounts at 60 days to 0.43 mg/kg at 40 days after band-furrow application (Sellers *et al.*, 1976). The half-life of the parent compound is approximately two weeks in sandy-loam soils (Labisky, 1975).

In a study of a variety of pesticides, Wauchope (1978) concluded that surface runoff from agricultural fields would be no more than 0.5% of the amount applied, unless rainfall was heavy within two weeks of application. If rainfall does occur within two weeks of application, there may be a loss of up to 20% of highly mobile chemicals through runoff. Sheehan *et al.* (1986) estimated that runoff would contribute as much as 50% of the total pesticide input in Canadian prairie wetlands following a "catastrophic" runoff event. The primary factors that affect the amount of a chemical that is lost in runoff are: 1) the properties of the chemical and its formulation; 2) the intensity, duration, and timing of rainfall; and 3) the characteristics of the soil drainage system (Willis and McDowell, 1982).

The proximity of wetlands to agricultural fields increases risks of environmental contamination through pesticides because of the potential for runoff and flooding. Grue *et al.* (1986) identified applications of pesticides to cultivated wetland basins as a significant route for pesticide entry into wetlands. Depending on seasonal precipitation, large numbers of temporary, seasonal and semipermanent wetlands may be cultivated and their basins treated with agricultural chemicals. In years with normal precipitation, one-third of all prairie-pothole wetlands may become dry enough to be cultivated; in a dry year, it may be possible to cultivate up to two-thirds of these wetlands (Smith *et al.*, 1964). In addition, permanent wetlands are often bordered by crop fields and therefore subject to runoff of agricultural chemicals. In 1985, 94% of the Waterfowl Production Areas of central North Dakota were adjacent to cropland, and 37% were completely surrounded by cropland (Grue *et al.*, 1986).

Wildlife Mortality

A National Agricultural Pesticide Impact Assessment Program (NAPIAP) survey of state and federal agency personnel was conducted to obtain an estimate of wildlife mortality attributable to exposure to phorate and terbufos (Table 30). The agencies included in this survey were: regional offices of the Environmental Contaminants Section, U.S. Department of Interior/Fish and Wildlife Service (USFWS); state directors of the Animal Damage Control Section, U.S. Department of Agriculture/Animal and Plant Health Inspection Service (USDA/APHIS/ADC); state wildlife specialists, Cooperative Extension Service (CES); and the following departments at the state level: Agriculture (DOA), Conservation, Environmental Control, Environmental Protection, Fish and Game, and Natural Resources. The survey requested information and documentation regarding wildlife mortality due to terbufos and phorate exposure. The survey requested specific information about crop or site, formulation, application method, accordance with label requirements, wildlife species and number of individuals killed, and other associated details. The survey was mailed June 25, 1990 with a response requested no later than July 18, 1990. A follow-up survey was mailed to 20% of the non-respondents, chosen at random, on August 27, 1990 with a response requested no later than September 10, 1990.

Most responses to the survey were received from CES (29.5%) and state agencies responsible for management of natural resources and environmental protection programs (28.3%). Additional responses were received from USDA/APHIS/ADC (17.6%), state DOA (17.0%), USFWS (4.5%), and universities (3.1%).

Table 30. Summary of results from a survey of state and federal wildlife specialists regarding wildlife mortality due to phorate and terbufos[a]

	Number	Percent
Surveys sent	317	---
Surveys returned	154	49
States reporting	50	100
Respondents having no documentation	142	92
Respondents having documentation on phorate	10	6
total phorate incidents	11	---
phorate incidents where label was followed[b]	1	9
Respondents having documentation on terbufos	2	1
total terbufos incidents	4	---
terbufos incidents where label followed	4	100
Total incidents reported	15	

[a]Source: NAPIAP Phorate and Terbufos Surveys, 1990.
[b]In six of the eleven reported incidents, it was unknown whether phorate was applied according to label recommendations; however, three of the six may have been in accordance.

The follow-up survey of non-respondents yielded no additional incidents and their responses were similar to 92.2% of the responses in the initial survey.

The following 10 respondents to the NAPIAP survey reported a total of 11 incidents of non-target mortality caused by phorate: California DOA; California Extension Service; California Fish and Game; Georgia DOA; South Dakota DOA; South Dakota Game and Fish; South Dakota USFWS; South Dakota USDA/APHIS/ADC; Region 6 USFWS; and the Wisconsin Department of Natural Resources. The following non-target animals were killed in the 11 wildlife mortality incidents that involved phorate: 2,065 songbirds (Passeriformes (ocines) spp.); 729 waterfowl (including 279 mallards); 270 gulls, shorebirds and wading birds (Charadriiformes spp. and Ciconiiformes spp.); 22 raptors (Falconiformes spp.) (including seven bald eagles (*Haliaeetus leucocephalus*)); three upland gamebirds (Phasianidae spp.); four mammals; and 20,000 mosquito fish (*Gambusia affinis*) and mollies (*Poecilia* spp.). In two incidents, animals were observed feeding directly on the treated crops. The time span between application and mortality ranged from five minutes to six months. Residue analyses were conducted in all 11 incidents but results were not reported.

Phorate was involved in incidents on the following crops (the number of incidents follows the crop): wheat (4), alfalfa (2), unknown (2), corn (1), and sugar beets (1). The factors associated with these incidents include: runoff after heavy rains (4), runoff from irrigation (2), spilled or partially empty bags left in field (2), surface application (2), and application in a wetland (1). In one incident, 4,500 gallons of phorate concentrate was spilled into a water drainage area after a commercial transport accident. One of the 11 incidents involving phorate was in accordance with the label, while 4 were not in accordance. It is unknown whether the remaining 6 reported incidents were in accordance with label recommendations; however, it was reported that three of the 6 may have been in accordance. Recommendations made by respondents included: follow label recommendations (4), prevent runoff (3), avoid use of pesticides in wetlands (3), prohibit use near waterfowl areas (2), incorporate into the soil (1), and contain spills (1).

Two respondents (North Carolina DOA/Pesticide Section, Ohio DOA/Pesticide Regulation) identified four incidents in which terbufos (Counter 15-G) caused non-target mortalities after application to corn (in-furrow) in accordance with label directions. A total of 3,000 bream

(*Lepomis* spp.), 12 crayfish (*Orconectes* spp.), and 1 black snake (*Elaphe obsoleta*) were killed in these four incidents. In each incident, heavy rains followed application, resulting in runoff of terbufos into nearby ponds or waterways. The time span between application and mortality was from 4 to 15 days. No animals were observed feeding directly on the pesticide or the treated crops. Residue analyses were conducted in all incidents but results were not reported.

The movement of phorate and terbufos through runoff and their presence in standing water poses a threat to wildlife. Eight of 11 (73%) phorate incidents and 4 of 4 (100%) terbufos incidents were associated with runoff or standing water caused by rainfall or irrigation. The moderate to high soil adsorption coefficient of phorate suggests that soil particle runoff would be significant only when precipitation was heavy (Kenaga, 1980).

Two wildlife mortality incidents occurred when phorate was not incorporated after application. One incident involved an aerial application to a crop field while the other was an inadvertent application to a field road. Neither of these applications were in accordance with the product label. Labisky (1975) conducted a simulated field study in which confined ring-necked pheasants (*Phasianus colchicus*) were exposed to terbufos granules pressed into the soil at rates of 1 and 5 lb technical per acre. The pheasants were exposed dermally through dusting behavior and possibly through ingestion, but ingestion was not observed. After two months, no mortality or signs of acute or chronic poisoning were observed. Based on these results and the results of the NAPIAP survey, there does not appear to be a significant threat to wildlife due to direct exposure and ingestion of phorate and terbufos granules if the granules are incorporated into the soil according to label recommendations.

Environmental Concerns Regarding Usage

A second NAPIAP survey was conducted to obtain information regarding the concerns of commodity specialists regarding the economic aspects of phorate and terbufos usage. The following question on environmental concerns was included:

> *"Are there any environmental reasons that would deter you from recommending terbufos/phorate?"*

In addition, the corn/sorghum group asked the following question:

> *"Are you aware of any bird or other wildlife kills caused by the use of granular formulations of phorate or terbufos in your state? If yes, please list the number of incidents, species involved, and the cause."*

Most (93%) of the commodity specialists who responded to the survey did not express concerns regarding the effects of phorate and terbufos on the environment. The major environmental concerns that were expressed by the commodity specialists were (number of respondents in parentheses): surface and groundwater contamination and runoff (6); hazards to wildlife (5); and lack of incorporation of granules (3). The results of the survey are summarized below.

Corn and Sorghum: 31 states responding

Illinois and Indiana noted environmental concerns regarding the use of phorate or terbufos. Indiana was concerned about the potential for runoff, while Illinois was concerned about the

high toxicity to mammals. Both states suggested that phorate and terbufos not be used near bodies of water. When asked to identify any bird or wildlife kills caused by phorate or terbufos, South Dakota noted three incidents of bird or wildlife mortality caused by phorate (corroborated by the survey of agency personnel) and Ohio noted that fish kills caused by terbufos occur rarely.

Cotton: 16 states responding

Mississippi, New Mexico, and Oklahoma noted environmental concerns regarding the use of phorate. Their concerns included the increased exposure risks to birds and other wildlife, high mammalian toxicity, and an increased risk to the environment.

Peanut: 8 states responding

No environmental concerns regarding the use of phorate were expressed.

Soybean: 39 states responding

Arkansas and Tennessee noted environmental concerns regarding the use of phorate. Their primary concern was related to increased environmental hazards to fish, birds, and other wildlife.

Beans: 20 states responding

No environmental concerns regarding the use of phorate were expressed.

Potato: 22 states responding

Louisiana and Maine expressed concern regarding the effect of phorate usage on 1) surface and groundwater contamination, and 2) birds.

Sugarbeet: 10 (phorate) and 9 (terbufos) states responding

No environmental concerns regarding the use of phorate or terbufos were expressed.

Wheat: 11 states responding

Missouri and Montana expressed concern regarding the effect of phorate usage on 1) groundwater supplies, and 2) wildlife when granules are not completely covered with soil.

Summary

A total of 154 individuals representing federal and state agencies in 50 states responded to a survey to determine the effects of phorate and terbufos usage on wildlife. Ninety-two percent (142) of the respondents had no information or documentation of wildlife mortality due to phorate or terbufos usage. These results suggest that environmental problems associated with the application of these chemicals are uncommon. However, these data must be interpreted with caution since a significant amount of wildlife mortality caused by pesticide exposure goes unnoticed or unreported.

Four incidents were reported in which wildlife mortality resulted from the application of terbufos. In each incident, terbufos was incorporated into the soil according to label directions, but heavy rains caused runoff and transportation of the pesticide to surface water or wetland areas where it was a hazard to wildlife. Eleven incidents occurred in which wildlife mortality resulted from applications of phorate. Four of these incidents were in accordance with label directions. One of the 11 incidents involving phorate was in accordance with the label, while 4 were not in accordance. It is not known with certainty whether the remaining six incidents were in accordance with label recommendations; however, three of the six may have been in accordance. Six of the incidents were confounded by heavy rains or irrigation which resulted in runoff or flooding. It appears that transportation of phorate and terbufos poses a hazard to wildlife when heavy rains or irrigation cause runoff or flooding. For this reason, the labels of phorate and terbufos should be modified by crop or registered site to limit or restrict their use on sites that have a high potential for flooding or excessive runoff. Factors that should be considered include seasonal rainfall patterns, proximity of the groundwater table to the soil surface, susceptibility of soil types to erosion, and slope of the soil surface. In 9 of the 11 wildlife mortality incidents that were reported in the NAPIAP survey, phorate granules were not incorporated into the soil. It is apparent that incorporation of these chemicals into the soil is an important precaution against wildlife mortality.

[illegible] were [illegible] respectively.
[illegible] the effects of phorate and [illegible] on wildlife. Ninety two percent [illegible] as intermediate [illegible] of wildlife mortality due to [illegible] usage. These results suggest that [illegible] potential [illegible] of these chemicals are [illegible] more [illegible] than [illegible] of wildlife [illegible] compared [illegible] pesticide [illegible] reported.

[illegible] were reported in which wildlife mortality [illegible] from the application of [illegible] terbufos was incorporated [illegible] and transportation of the [illegible] to wildlife. Eleven incidents [illegible] phorate. Four of these incidents [illegible] of the 11 incidents involving phorate [illegible] It is not known with certainty [illegible] with label recommendations, however [illegible] the incidents were [illegible] It appears that transportation [illegible] phorate and [illegible] rains or irrigation cause runoff or flooding [illegible] should be modified by [illegible] a high potential for flooding or excessive runoff. Factors that [illegible] patterns, proximity of [illegible] of soil [illegible] and slope of the [illegible] incidents that were reported in the NAWAP [illegible] It is apparent that incorporation of these [illegible] against wildlife mortality.

Literature Cited

Almand, L.K., D.G. Bottrell, J.R. Cate, Jr., H.E. Daniels, and J.G. Thomas. 1969. Greenbugs on sorghum and small grains. Tex. Agric. Ext. Ser. L-819.

American Cyanamid Company. 1986. Material Safety Data Sheet Number 1311-02. American Cyanamid Company Agricultural Division, Crop Protection Chemicals Department, Wayne, New Jersey.

American Cyanamid Company. 1987. Material Safety Data Sheet Number 0663-02. American Cyanamid Company Agricultural Division, Crop Protection Chemicals Department, Wayne, New Jersey.

American Cyanamid Company. 1989a. Material Safety Data Sheet Number 1992-05. American Cyanamid Company Agricultural Division, Crop Protection Chemicals Department, Wayne, New Jersey.

American Cyanamid Company. 1989b. Material Safety Data Sheet Number 9977-03. American Cyanamid Company Agricultural Division, Crop Protection Chemicals Department, Wayne, New Jersey.

American Cyanamid Company. 1990. Counter Technical Information. American Cyanamid Agricultural Division, Crop Protection Chemicals Department, Wayne, New York.

American Cyanamid Company. 1990. Thimet Technical Information. American Cyanamid Agricultural Division, Crop Protection Chemicals Department, Wayne, New Jersey.

Annual Crop Summary. 1986. Agricultural Statistics Board, National Agricultural Statistics Service, U.S. Department of Agriculture, Washington, D.C.

Anonymous. 1990. Sorghum insect management for 1990. Kansas State University, Entomology 140, Kansas Cooperative Extension Service, MF-742 (Revised).

Bauernfeind, R.J. 1977. Insecticide resistance and the control of green peach aphids in Wisconsin: effect on the incidence of potato leafroll virus. Ph.D. thesis, University of Wisconsin, Madison, Wisconsin.

Bechinski, E.J., D.O. Everson, C.D. McNeal and J.J. Gallian. 1990. Forecasting peak seasonal capture of sugarbeet root maggot (Diptera: Otitidae) with sticky-stake traps in Idaho. J. Econ. Entomol. 83:2078-2085.

Bechinski, E.J., C.D. McNeal and J.J. Gallian. 1989. Development of action thresholds for the sugarbeet root maggot (Diptera: Otitidae). J. Econ. Entomol. 82:608-615.

Boetel, M.A., B.W. Fuller and D.D. Walgenbach. 1990. Comparative efficacy of corn rootworm insecticide rates in South Dakota, 1989. Pages 180-184 *In* Insecticide & Acaricide Tests: 1990, Vol. 15. Entomological Society of America, College Park, Maryland.

Bowman, J.S. and J.E. Casida. 1958. Further studies on the metabolism of thimet by plants, insects, and mammals. J. Econ. Entomol. 51:838-843.

Brandenburg, R.L. 1990. Peanut insect management. Pages 32-41 *In* Peanuts 1990. N.C. Agric. Ext. Serv. AG-94.

Branson, T.F. and E.E. Ortman. 1970. The host range of larvae of the western corn rootworm: Further studies. J. Econ. Entomol. 63:800-803.

Branson, T.F., V.A. Welch, G.R. Sutter, and J.R. Fisher. 1983. Resistance to larvae of *Diabrotica virgifera virgifera* in three experimental maize hybrids. Environ. Entomol. 12:1509-1512.

Brooks, H.L. 1967. The effect of planting date, irrigation, and two corn varieties on populations of western corn rootworms, *Diabrotica virgifera*. Ph.D. Dissertation, Kansas State University, Manhattan, Kansas.

Campbell, W.V. and D.A. Emery. 1967. Some environmental factors affecting feeding, oviposition, and survival of the southern corn rootworm. J. Econ. Entomol. 60:1675-1678.

Carter, F.L., N.P. Tugwell and J.R. Phillips. 1989. Pages 295-297 *In* J.M. Brown (Ed.) Thrips Control Strategy: Effects On Crop Growth, Yield, Maturity and Quality. Beltwide Cotton Production Research Conference. National Cotton Council of America, Memphis, Tennessee.

Chaddha, S. and K. Ostlie. 1990. Corn rootworm control: 1989. Pages 185-186 *In* Insecticide and Acaricide Tests: 1990, Vol. 15. Entomological Society of America, College Park, Maryland.

Chester, K.S. 1950. Diseases caused by bacteria. Page 282-284 *In* Nature and Prevention of Plant diseases, 2nd Ed. McGraw Hill Book Co. Inc., New York.

Chiang, H.C. 1973. Bionomics of the northern and western corn rootworms. Ann. Rev. Entomol. 18:47-72.

Coale, F.J. and O. Sosa, Jr. 1990. Sugarcane yield response to soil insecticides in the Everglades agricultural area. J. Am. Soc. of Sugarcane Tech. (*In press*)

Colorado Agricultural Statistics Service. 1990. Colorado Agricultural Statistics. Colorado Statistics Service, Lakewood, Colorado.

Cooperative Extension Service. 1985. The Montana Small Grain Guide. Cooperative Extension and Agricultural Experiment Station, Montana State University, Bull 364. Bozeman, Montana.

Crittenden, H.W., K.M. Hastings and D.M Moore. 1966. Soybean losses caused by tobacco ringspot virus. Plant Dis. Rep. 50:910-913.

Crop Protection Chemicals Reference, 5th ed. 1989. Chemical and Pharmaceutical Press, John Wiley and Sons, New York.

Dickson, D.W. and T.E. Hewlett. 1987. Effect of two nonfumigant nematicides on corn grown in two adjacent fields infested with different nematodes. Ann. Appl. Nematology 1:89-93.

Dixon, G.A. Olonju, P.J. Bramel-Cox, J.C. Reese, and T.L. Harvey. 1990. Mechanisms of resistance and their interactions in twelve sources of resistance to biotype E greenbug in sorghum. J. Econ. Entomol. 83:234-240.

Douglas, J.R. and W.C. Cook. 1954. The beet leafhopper. U.S. Department of Agriculture, Circ. 542.

Drees, B. 1988. Sorghum and corn seed feeding by foraging red imported fire ant workers and the impact of seed protecting insecticides. Texas A & M Ag. Ext. Ser. Misc. Rpt.

Dunning, A. and W. Byford. 1982. Pests, Diseases and Disorders of Sugar Beet. B.M. Press, Sartrouville, France.

Ferro, D.N. 1985. Pest status and control strategies of the Colorado potato beetle. Mass. Ag. Exp. Sta. Res. Bull. 704:1-8.

Ferro, D.N. and W.D. Gelerntner. 1989. Toxicity of a new strain of *Bacillus thuringiensis* to Colorado potato beetle. J. Econ. Entomol. 82:750-755.

Forgash, A.J. 1985. Insecticide resistance in the Colorado potato beetle. Mass. Ag. Exp. Sta. Res. Bull. 704:33-52.

Foster, R.F. and J.J. Tollefson. 1986. Frequency and severity of attack of several pest insects on corn in Iowa. J. Kansas Entomol. Soc. 59:269-274.

French, J.C. 1989. Multistate Projection Incidence of Tomato Spotted Wilt Disease on Peanuts and Other Crops. FY-89 Annual Progress Report, Auburn University, Auburn, Alabama.

Fuchs, T.W., H.A. Turney, J.G. Thomas, and G.L. Teetes. 1988. Managing insect and mite pests of sorghum. Texas Agricultural Extension Service, College Station, Texas.

Genung, W.G. 1970. Flooding experiments for control of wireworms attacking vegetables in the Everglades. Florida Entomol. 53:55-63.

Getzin, L.W. and C.H. Shanks. 1970. Persistence, degradation, and bioactivity of phorate and its oxidative analogues in soil. J. Econ. Entomol. 63:52-58.

Gohlich, H. 1983. Formation of drift and basic considerations in its reduction. Int. Union Pure Appl. Chem. 4:271-280.

Grafius, E., P. Ionnidis and B. Bishop. 1988. Management of Colorado potato beetle. Pages 73-84 *In* Michigan Potato Research Report. Michigan State University, Ann Arbor, Michigan.

Gray, M.E., K. Steffey and K. Kinney. 1990. Corn rootworm soil insecticides: Are the current application rates necessary? Pages 35-52 *In* Proceeding of the Illinois Agricultural Pesticide Conference. Coop. Extension Serv., Univ. of Illinois, Urbana-Champaign, Illinois.

Greene, C.R., R.A. Kramer, G.W. Norton, E.G. Rajotte and R.M. McPherson. 1985. An economic analysis of soybean integrated pest management. Amer. J. Agr. Econ. 67:568-572.

Gregory, W.W. and G.J. Musick. 1976. Insect management in reduced tillage systems. Bull. Entomol. Soc. Am. 22:302-304.

Grue, C.E., L.R. DeWeese, P. Mineau, G.A. Swanson, J.R. Foster, P.M. Arnold, J.N. Huckins, P.J. Sheehan, W.K. Marshall and A.P Ludden. 1986. Potential impacts of agricultural chemicals on waterfowl and other wildlife inhabiting prairie wetlands: An evaluation of research needs and approaches. Trans. N. Amer. Wildl. and Nat. Resour. Conf. 51:357-383.

Grue, C.E., W.J. Fleming, D.G. Busby and E.F. Hill. 1983. Assessing hazards of organophosphate pesticides to wildlife. Trans. N. Amer. Wildl. and Nat. Resour. Conf. 48:200-220.

Grue, C.E. and B.K. Shipley. 1984. Sensitivity of nestling and adult starlings to dicrotophos, an organophosphate pesticide. Environ. Res. 35:454-465.

Hall, D.G. 1985. Damage by the corn wireworm *Melanotus communis* to plant cane during germination and early growth. Journal of American Society of Sugarcane Technology 4:13-17.

Hall, D.G. 1989. Stand reductions caused by the wireworm *Melanotus communis* infesting plant cane in Florida, Yield loss wireworm density relationship. Sugar ỳ Azucar 84:37-38.

Hall, D.G., and R.H. Cherry. 1985. Contact toxicities of eight insecticides to the wireworm *Melanotus communis* (Coleoptera: Elateridae). The Florida Entomologist 68:350-352.

Head, R.B. 1990a. Cotton Insect Control Guide. Mississippi Cooperative Extension Service Publ. 343. Mississippi State University, Mississippi State, Mississippi.

Head, R.B. 1990b. Cotton Insect Losses. *In* J.M. Brown (Ed.) Report of the Cotton Insect Losses Committee. Beltwide Cotton Production Research Conference. National Cotton Council of America, Memphis, Tennessee. (*In press*)

Hein, G.L. 1984. Adult population dynamics and oviposition of northern and western corn rootworms in continuous cornfields under commercial production. Ph.D. Dissertation, Iowa State University, Ames, Iowa.

Hein, G.L. 1990. Corn root protection against corn rootworm larvae, 1988. Pages 193-194 *In* Insecticide and Acaricide Tests: 1990, Vol. 15. Entomological Society of America, College Park, Maryland.

Hein, G.L., M.K. Bergman, R.G. Bruss and J.J. Tollefson. 1985. Absolute sampling technique for corn rootworm (Coleoptera: Chrysomelidae) adult emergence that adjusts to fit common-row spacing. J. Econ. Entomol. 78:1503-1506.

Hein, G.L. and J.J. Tollefson. 1984. Comparison of adult corn rootworm (Coleoptera: Chrysomelidae) trapping techniques as population estimators. Environ. Entomol. 13:266-271.

Hein, G.L. and J.J. Tollefson. 1985a. Seasonal oviposition of northern and western corn rootworms (Coleoptera: Chrysomelidae) in continuous cornfields. J. Econ. Entomol. 78:1238-1241.

[illegible] W. and G. J. Musick. 19[illegible] [illegible] Entomol. Soc. Am. 22:302-304.

[illegible], L. R. DeWeese, [illegible] [illegible] W. K. Manfred and [illegible] [illegible] on waterfowl [illegible] needs and application [illegible]

[illegible] E. W. J. Fleming [illegible] [illegible] 200-220.

[illegible] and B. F. Shipley [illegible] [illegible]

[illegible] 1985. Damage [illegible] [illegible]

[illegible] G. 1989. Seed requirements [illegible]

[illegible] G. and [illegible] 1985. [illegible] [illegible] corn [illegible]

[illegible] 1990. Cotton Insect Control [illegible] 149. Mississippi [illegible]

[illegible] 1990. Cotton insect losses [illegible] [illegible] of America [illegible]

[illegible] 1984. Adult population dynamics and oviposition [illegible] in continuous corn [illegible] [illegible] University, Ames, Iowa.

[illegible] 1986. Corn root protection against [illegible] [illegible] and Acaricide Tests [illegible] 15 [illegible]

[illegible] A. K. Bergman, R. E. Buss and [illegible] Tollefson. 1985. [illegible] (Coleoptera: Chrysomelidae) adult emergence [illegible] row spacing. J. Econ. Entomol. 78:1503-1506.

[illegible] J. J. Tollefson. 1984. Comparison of adult corn rootworm (Col[illegible] [illegible] trapping techniques as population estimators. Environ. Ent[illegible] [illegible]71.

[illegible] J. Tollefson. 1985a. Seasonal oviposition of northern and western [illegible] (Coleoptera: Chrysomelidae) in continuous cornfields. J. Econ. Entom[illegible]

Hein, G.L., and J.J. Tollefson. 1985b. Use of the Pherocon AM trap as a scouting tool for predicting damage by corn rootworm (Coleoptera: Chrysomelidae) larvae. J. Econ. Entomol. 78:200-203.

Hill, E.F. and W.J. Fleming. 1982. Anticholinesterase poisoning of birds: field monitoring and diagnosis of acute poisoning. Environ. Toxicol. Chem. 1:27-38.

Hill, R.E. and Z.B. Mayo. 1980. Distribution and abundance of corn rootworm species as influenced by topography and crop rotation in eastern Nebraska. Environ. Entomol. 9:122-127.

Hoffman, D.J. and P.H. Albers. 1984. Evaluation of potential embryotoxicity and teratogenicity of 42 herbicides, insecticides, and petroleum contaminants to mallard eggs. Arch. Environ. Contam. Toxicol. 13:15-27.

Hower, A.A. and S. Alexander. 1990. Corn rootworm larval control. 1989. Pages 194-195 *In* Insecticide and Acaricide Tests: 1990, Vol. 15. Entomological Society of America, College Park, Maryland.

Horn, D.J. 1988. Pages 146-149 *In* Ecological Approach to Pest Management. Guilford Press, New York.

Hunt, T.N. and J.R. Baker. 1982. Insect and related pests of field crops: some important, common and potential pests in North Carolina. N.C. Agric. Ext. Serv. AG-271.

Irwin, M.E. and K.V. Yeargan. 1980. Sampling phytophagous thrips on soybeans. Page 284 *In* M. Kogan and D.C. Herzog (Eds.) Sampling Methods in Soybean Entomology. Springer-Verlag, New York.

Jansson, R.K., S.H. Lecrone, and R.H. Cherry. 1988. Comparative toxicities of fonofos and phorate to different populations of *Melanotus communis* (Gyllenhal) (Coleoptera:Elateridae) in southern Florida. The Canadian Entomologist 120:397-400.

Jarvi, K. 1990. Corn rootworm control, 1989. Page 195 *In* Insecticide and Acaricide Tests: 1990, Vol. 15. Entomological Society of America, College Park, Maryland.

Johnson, F.A., D.E. Short and P.G. Koehler (Eds.). 1990. Florida Insect Control Guide. Florida Cooperative Extension Service, University of Florida, Gainesville, Florida.

Johnston, R.L. and L.E. Sandvol. 1986. Susceptibility of Idaho populations of Colorado potato beetle to four classes of insecticides. Am. Potato J. 63:81-85.

Karr, L.L. 1984. Temporal efficiency of the Pherocon AM trap for adult corn rootworm sampling. M.S. Thesis, Iowa State University, Ames, Iowa.

Kenaga, E.E. 1980. Predicted bioconcentration factors and soil sorption coefficients of pesticides and other chemicals. Ecotoxicol. Environ. Safety 4:26-38.

Kenimer, A.L., J.K. Mitchell and A.S. Felsot. 1989. Pesticide formulation and application technique effects on surface pesticide transport. Paper No.892506, presented at American Soc. of Ag. Engineers, New Orleans, Louisiana, December 12-15, 1989.

Krysan, J.L., D.E. Foster, T.F. Branson, K.R. Ostlie and W.S. Cranshaw. 1986. Two years before the hatch: rootworms adapt to crop rotation. Bull. Entomol. Soc. Am. 32:250-253.

Krysan, J.L., and T.A. Miller (Eds.). 1986. Methods for the study of pest Diabrotica. Springer-Verlag, New York.

Krysan, J.L. and G.R. Sutter. 1986. Aldrin susceptibility as an indicator of geographic variability in the northern corn rootworm, Diabrotica barberi (Coleoptera: Chrysomelidae). Environ. Entomol. 15:427-430.

Labisky, R.F. 1975. Response of pheasants to simulated field applications of counter, an organophosphate insecticide. J. Wildl. Manage. 39:174-178.

Lance, D.R. 1988. Potential of 8-methyl-2-decyl propanoate and plant-derived volatiles for attracting corn rootworm beetles (Coleoptera: Chrysomelidae) to toxic bait. J. Econ. Entomol. 81:1359-1362.

Landis, B.J. and J.A. Onsager. 1977. Wireworms on Irrigated Lands in the West: How to Control Them. United States Department of Agriculture, Agric. Res. Serv., Farmers Bull. 2220.

Lashomb, J.H. and Y.S. Ng. 1984. Colonization by Colorado potato beetle in rotated and non-rotated potato fields. Environ. Entomol. 13:1352-1356.

Laveglia, J. and P.A. Dahm. 1975. Oxidation of terbufos (counter) in three Iowa surface soils. Environ. Entomol. 4:715-718.

Leser, J.F. 1986. Thrips Management: Problems and Progress. Pages 175-179 *In* J.M. Brown (Ed.) Proceedings of the Cotton Production Research Conference. Beltwide Cotton Production Research Conference. Cotton Council of America, Memphis, Tennessee.

Longridge, J.L., J.A. Wyman and L.L. Reuter. 1989. Vegetable Crops. Entomology Field Research Project Report. University of Wisconsin, College of Agriculture and Life Sciences, Madison, Wisconsin.

Luckmann, W.H. 1978. Insect control in corn, practices and prospects. Pages 137-155 *In* E.H. Smith and D. Pinmentel (Eds.) Pest Control Strategies. Academic Press, New York.

McBride, D.K. 1983. Wireworm control trials in corn. N. Dak. Farm Res. Bimonthly Bull. 40:10-13.

McBride, D.K. 1984. White grub control trials in corn. N. Dak. Farm Res. Bimonthly Bull. 41:8-10.

McCarty, R.T., M. Haufler and C.A. McBeth. 1969. Response of sheep grazing forage sprayed with phorate or mevinphos. J. Am. Vet. Med. Assoc. 154:1557-1580.

Meehan, M. and G. Wilde. 1989. Screening for sorghum line and hybrid resistance to chinch bug (Hemiptera: Lygaeidae) in the greenhouse and growth chamber. J. Econ. Entomol. 82:616-620.

Meinke, L. 1990. Potential of starch encapsulated semiochemical/insecticide formulations for corn rootworm control. Pages 107-111 *In* Proceedings of the Illinois Agricultural Pesticide Conference. Coop. Extension Serv., Univ. of Illinois, Urbana-Champaign, Illinois.

Metcalf, C.L., W.P. Flint and R.L. Metcalf. 1962. Destructive and Useful Insects, 4th ed. McGraw-Hill Book Co., New York.

Metcalf, R.L. and W.H. Luckman. 1982. Introduction to Insect Pest Management, Page 577. John Wiley & Sons, New York.

Michigan State University. 1989a. Phorate. *In* Extension Toxicology Network (Extoxnet). Michigan State University, East Lansing, Michigan.

Michigan State University. 1989b. Terbufos. *In* Extension Toxicology Network (Extoxnet). Michigan State University, East Lansing, Michigan.

Mueller, A.J. and R.G. Luttrell. 1977. Thrips on soybeans. Arkansas Farm Res. 4:7.

Negron, J.F. and T.J. Riley. 1988. Chinch bug control in sorghum with granular insecticides. Page 276 *In* Insecticide and Acaricide Tests, Vol. 13. Entomological Society of America, College Park, Maryland.

Oleson, J.D., J.M. Gifford, B.P. Spike and J.J. Tollefson. 1990. Corn rootworm larval control, 1989. Pages 206-209 *In* Insecticide & Acaricide Tests: 1990, Vol. 15. Entomological Society of America, College Park, Maryland.

Ostlie, K.R., Y. Hwang and S. Chadda. 1990. Wireworm control in replanted corn. 1989. Page 210 *In* Insecticide and Acaricide Tests, Vol. 15. Entomological Society of America, College Park, Maryland.

Parker, R.D., M. Treacy and J.D. Janak. 1989. Control of Chinch Bug. Page 270 *In* Insecticide and Acaricides Tests, Vol. 14. Entomological Society of America, College Park, Maryland.

Pattee, H.E. and C.T. Young (Eds.). 1982. Peanut Science and Technology. Amer. Peanut Res. Educ. Soc., Inc., Yoakum, Texas.

Pfadt, R.E. 1978. Fundamentals of Applied Entomology. MacMillian, Inc., New York.

Pfadt, R.E. 1985. Fundamentals of Applied Entomology, 4th ed. MacMillan Publ. Co., New York.

Radcliff, E.B. and C.G. Watrin. 1986. Pyrethroid resistance in Red River Valley potato beetles. Valley Potato Grower, Issue 2.

Robertson, L.S. and R.D. Frazier (Eds.). 1978. Dry Bean Production Principles and Practices. Cooperative Extension Service, Agricultural Experiment Station, Michigan State University, Extension Bull. E-1251.

Schwartz, H.F. and M.A. Brick (Eds.). 1990. Colorado Dry Bean Production and IPM bulletin. Colorado State University Cooperative Extension Service and Agricultural Experiment Station, Fort Collins, Extension Bull. 548A.

Schwartz, H.F. and M.A. Pastor-Corrales (Ed.). 1989. Bean Production Problems in the Tropics, 2nd ed. Centro International de Agricultural Tropical, Cali, Columbia.

Sellers, L.G., J.C. Owens, J.J. Tollefson and P.A. Dahm. 1976. Residues of terbufos (counter) in Iowa corn and soil. J. Econ. Entomol. 69:133-135.

Sheehan, P.K., A. Baril, P. Mineau, D.K. Smith and W.K. Marshall. 1986. The impact of pesticides on the ecology of prairie-nesting ducks. Unpublished report, Canadian Wildlife Service.

Smith, G.L. 1987. Pesticide use and toxicology in relation to wildlife organophosphorus and carbamate compounds. U.S. Fish and Wildlife Serv. Resour. Publ. 70, Washington, D.C.

Smith, J.C. 1972. Tobacco thrips - nematode control on Virginia-type peanuts. J. Econ. Entomol. 65:1700-1703.

Smith, A.G., J.H. Stoudt and J.B. Gollop. 1964. Prairie potholes and marshes. Pages 39-50 *In* J.P. Linduska (Ed.) Waterfowl Tomorrow. U.S. Fish and Wildlife Serv., Washington, D.C.

Spyker, J.M and D.L. Avery. 1977. Neurobehavioral effector prenatal exposure to the organophosphate diazinon in mice. J. Toxicol. Environ. Health 3:989-1002.

Steffey, K. and K. Kinney. 1988. Corn rootworm control: do root ratings tell the whole story? Pages 80-96 *In* Illinois Agricultural Pesticide Conference 1988. Summaries of papers presented at the Fortieth Spray School. Coop. Ext. Serv., Univ. of Illinois, Urbana-Champaign, Illinois.

Steffey, K., D. Kuhlman, K. Kinney and M. Gray. 1989. Management of corn rootworms: Research and recommendations. Pages 76-92 *In* Proceedings of the Illinois Agricultural Pesticide Conference. Coop. Extension Serv., Univ. of Illinois, Urbana-Champaign, Illinois.

Stevenson, W.R., L.V. Binning, D. Curwen, K.A. Kelling, J.A. Wyman and J.P. Koenig. 1990. Integrated crop management of potatoes *In* Potato Integrated Pest Management in the North Central United States. Proc. NCS-3, University of Minnesota, Minneapolis, Minnesota.

Storch, R.H. 1981. Insects and diseases in the production of seed potatoes. Pages 138-151 *In* J.H. Lashomb and R. Casagrande (Eds.) Advances in Potato Pest Management. Academic Press, New York.

Stromborg, K.L. 1981. Reproductive tests of diazinon on bobwhite quail. Pages 19-30 *In* D.W. Lamb and E.E. Kenaga (Eds.) Avian and Mammalian Wildlife Toxicology: Second Conference. ASTM 757. Am. Soc. for Testing and Materials, Philadelphia, Pennsylvania.

Tappan, W.B. and D.W. Gorbet. 1981. Economics of tobacco thrips control with systemic pesticides on Florunner peanuts in Florida. J. Econ. Entomol. 74:283-286.

Teetes, G.L. and J.W. Johnson. 1973. Damage assessment of the greenbug on grain sorghum. J. Econ. Entomol. 66:1181-1185.

Teetes, G.L., C.A. Schaffer, J.R. Gipson, R.C. McIntyre, and E. C. Latham. 1975. Greenbug resistance to organophosphorus insecticides on the Texas High Plains. J. Econ. Entomol. 68:214-216.

[illegible] and M.A. Pastor-Corrales [illegible]
[illegible] ed. Centro Internacional de Agricultura Tropical [illegible]

[illegible] C. Owens, J.J. Tollefson [illegible]
[illegible]-corn and soil [illegible] Econ. Ent[illegible]

[illegible]an, P.K. [illegible] A. Bent [illegible]
[illegible]
[illegible]vice.

[illegible], D.L. [illegible]
[illegible] compounds [illegible]

[illegible] 1972 [illegible]
[illegible] 65:1700-1703.

[illegible], A.G., J.H. Stout and J.B. [illegible]
[illegible] Lindquist (Ed.). Vol. [illegible]

[illegible] and D.I. Avery [illegible]
[illegible]ative Ceratom[illegible]

[illegible], P. and K. Kamm[illegible] [illegible]
[illegible]ans 80-99 in Illinois Agricultural Pest [illegible]
[illegible] at [illegible] spray School
[illegible]ana-Champaign, Illinois.

[illegible] Kuhlman, K. Kirby and [illegible]
[illegible] and soybean [illegible] 36 [illegible]
[illegible] Conference Coop. Extension [illegible]

[illegible]son, R., L.V. Blowing, B. [illegible]
[illegible]: 5 crop management [illegible] in Potato [illegible]
[illegible] States. Plan [illegible]

[illegible] 1981. Insects and diseases in the [illegible]
[illegible] and B. Casagrande (Eds.). Advances [illegible]
[illegible] Press, New York.

[illegible], K.L. 1981. Reproductive tests of [illegible] [illegible]
[illegible] and E.E. Kenaga (Eds.) Avian and Mammalian Wildlife [illegible]
[illegible] ASTM 757. Am. Soc. for Testing and Materials [illegible]

[illegible] D.W. Gorbet. 1981. Economics of tobacco thrips [illegible]
[illegible]s of Florunner peanuts in Florida. J. Econ. Entomol. [illegible] 233-2[illegible]

[illegible] and J.W. Johnson. 1973. [illegible] assessment of the [illegible]
J. Econ. Entomol. 66:1181-1185.

[illegible] C.A. Schaefer, J.R. G[illegible], C. [illegible], and [illegible] C. [illegible], 197[illegible]
[illegible] in organophosphorus insecticides of the Texas High Plains. [illegible] Entomol.

Tollefson, J.J. 1986. Field sampling of adult populations. Pages 123-146 *In* J.L. Krysan and T.A. Miller (Eds.) Methods for the Study of Pest Diabrotica. Springer-Verlag, New York.

Tollefson, J.J., J.C. Owens and J.F. Witkowski. 1975. Influence of sticky trap color and size on catch of corn rootworm adults. Proc. N. Cent. Br. Entomol. Soc. Am. 30:83.

USDA. 1954. Wireworms and their control on irrigated lands. F. Bull. 1866.

USDA. 1986a. Agricultural Statistics: 1986. National Agricultural Statistics Service, United States Department of Agriculture, Washington, D.C.

USDA. 1986b. Crop Production: 1985 Summary. National Agricultural Statistics Service, U.S. Department of Agriculture, Washington, D.C.

USDA. 1987. Agricultural Statistics: 1987. National Agricultural Statistics Service, United States Department of Agriculture, Washington, D.C.

USDA. 1988. Crop Production: 1987 Summary. National Agricultural Statistics Service, U.S. Department of Agriculture, Washington, D.C.

USDA. 1989a. Agricultural Statistics: 1989. National Agricultural Statistics Service, U.S. Department of Agriculture, Washington, D.C.

USDA. 1989b. The Biologic and Economic Assessment of Aldicarb. National Agricultural Pesticide Impact Assessment Program, U.S. Department of Agriculture, Washington, D.C.

USDA. 1989c. Farm Resources Income and Expenses: 1986-88. National Agricultural Statistics Service, U.S. Department of Agriculture, Washington, D.C.

USDA. 1990a. Agricultural Statistics: 1990. National Agricultural Statistics Service, U.S. Department of Agriculture, Washington, D.C.

USDA. 1990b. Crop Production: 1989 Summary. National Agricultural Statistics Service, U.S. Department of Agriculture, Washington, D.C.

Walker, C.H. 1983. Pesticides and birds---mechanisms of selective toxicity. Agric. Ecosystems and Environ. 9:211-226.

Walker, R.L. 1968. Flooding cane fields before planting. Sugar J. 31:28-30.

Walter-Echols, G. and E.P. Lichtenstein. 1978. Movement and metabolism of ^{14}C phorate in a flooded soil system. J. Agric. Food Chem. 26:599-604.

Ward, C.R., E.W. Muddleston, J.C. Owens, T.M. Mills, L.G. Richardson and D. Ashdown. 1972. J. Econ. Entomol. 65:523-529.

Wauchope, R.D. 1978. The pesticide content of surface water draining from agricultural fields---a review. J. Environ. Qual. 7:459-472.

Weeks, J.R., T.P. Mack, J.C. French and A.K. Hagan. 1988. Thrips control regimes targeted to reduce tomato spotted wilt virus on peanuts. Proc. Amer. Peanut Res. Educ. Soc. 20:17.

Wilde, G. and J. Morgan. 1978. Chinch bug on sorghum: chemical control, economic injury levels, plant resistance. J. Econ. Entomol. 71:908-910.

Willis, G.H. and L.L. McDowell. 1982. Review: pesticides in agricultural runoff and their effects on downstream water quality. Environ. Toxicol. Chem. 1:267-279.

Wright, R.J., S.D. Danielson, J.F. Witkowski, G.L. Hein, L.L. Peters, J.B. Campbell, F.P. Baxendale, A.F. Hagon, K.J. Jarvis, R.C. Seymour and J.A. Kalish. 1990. 1990 Insect management guide for Nebraska corn and sorghum. Nebraska Cooperative Extension, EC 90-1509.

Young, W.R. and G.L. Teetes. 1977. Sorghum Entomology. Annual Review of Entomology. 22:193-218.

Appendix I

Pesticides Under Review: Phorate and Terbufos

Crop/Site________________________

State________________________

Acreage of Crop Planted________________(3)

Production Unit________________________(4)

Target Pest(s)________________(1)

Years________________________(2)

(Average for years 1985-1989)

chemical or nonchemical alternatives (5)	% total acreage currently treated with (6)	% total acreage treated if terbufos is withdrawn (7)	% total acreage treated if phorate is withdrawn (7)	% total acreage treated if both phorate & terbufos is withdrawn (7)	method of app. (B or IF) (8)
terbufos		xxxxxx		xxxxxx	
phorate			xxxxxx	xxxxxx	
chlorpyrifos					
fonofos					
carbofuran					
tefluthrin					
other(s)					

Effect on yield if:		
terbufos is withdrawn (9)	phorate is withdrawn (9)	both terbufos & phorate are withdrawn (9)
±____%	±____%	±____%

Assume that during the past 5 years all granular formulations of soil insecticides were not available. What is your % estimate of this effect on yield?_______% (Assume liquid soil insecticides were available.)

Assume that during the past 5 years that both granular and liquid formulations of soil insecticides were not available. What is your % estimate of this effect on yield?_______%

Name of person supplying information:________________________________

Institution and address:________________________________

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